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DESIGN AND OPERATION OF ROCKY MOUNTAIN INFILTROMETER

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W. G. McGinnies, Director

DESIGN AND OPERATION OF ROCKY MOUNTAIN INFILTROMETER

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DESIGN AND OPERATION OF ROCKY MOUNTAIN INFILTROMETER

by

E. J. Dortignac[1]

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The Rocky Mountain infiltrometer originally designed and tested by Wilm et al (22) and described by Wilm (21), originated from the type FA developed by the Flood Control group of the Soil Conservation Service. This modified infiltrometer is considerably different from the FA,[2] about the only similarity being that it employs a type F nozzle and the plot frame area approximates 2.5 square feet. The writer has used this instrument since 1946 and added numerous revisions and modifications. All equipment has been streamlined and lightened for ease in handling and carrying. In addition, a plan for placement of equipment on the 1½-ton truck simplifies and speeds up repeated loading and unloading of equipment, allowing a greater number of samples per unit time. Another innovation is the use of this instrument for measurement of rates of erosion in addition to infiltration rates. This infiltrometer can be used successfully for this latter objective though the standard deviation of measurement is greater than for infiltration rates. These larger variations are no doubt associated with variations in slope and rain intensity. Whereas these factors do not influence water-absorption rates (3,4,5,11) it has been demonstrated that they do influence erosion losses (4,11). Neal (11) working with a single soil type, Putnam silt loam, found under laboratory conditions that soil losses from a saturated soil increased as the 0.7 power of the slope percent and the 2.2 power of the rain intensity.

An insufficient number of field runs and analyses have been conducted thus far with the Rocky Mountain infiltrometer to test these formulae under field conditions. Considerably more field work and experimentation is planned and it is believed that instrumental error can be reduced to that consistent with infiltration rates. A report on this phase of the work will be prepared at a later date.

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[1] Forester, Rocky Mountain Forest and Range Experiment Station, maintained by U. S. Department of Agriculture, Forest Service, in cooperation with Colorado A & M College at Fort Collins, Colorado.

[2] FA instrument is a modified North Fork infiltrometer (13). Main changes in North Fork instrumentation is substitution of F nozzles in place of standard fog nozzles and replacement of hand-operated pump with a power pump.

DESCRIPTION OF INFILTROMETER EQUIPMENT

The complete Rocky Mountain infiltrometer consists of the following major items:

1. Power pump
2. 1½-ton truck with mounted 400-500 gallon capacity storage tank
3. Portable metal plot frames, rainfall troughs, and rain applicators
4. Circulating system
5. Calibration equipment
6. Windbreaker tents and canvas plot covers
7. Collector and sedimeht cans, graduates, and trays.

A complete list of items is contained in the Appendix. The assembled equipment is shown in figure 1. A general description and photograph of each major item is given in the following text. Specific details, plans for construction and costs are given in the Appendix.

POWER PUMPS AND THEIR OPERATION

The pump is used to supply water to the rainfall sprinklers which produce the artificial rainfall pattern. In sprinkling experimental plot areas it is essential that the rate of application be constant. For this reason the pump must be capable of continuous operation for several hours without appreciable change in the developed pressure. It is preferable that the pump be powered by a gasoline engine. When tests are to be conducted at high altitudes, it is well to consider the decreased efficiency of gasoline engines. An average engine decreases in horsepower output approximately 3 percent for each 1,000 feet above sea level.

Under certain conditions, the pump may have to be carried by hand over rough terrain and for considerable distances. It should therefore be as light and compact as possible without sacrificing strength and reliability. Moreover, a light, compact pump is desirable for mounting on a truck so as to provide maximum storage space for other equipment and a minimum load. It should be exceptionally dependable in operation. Breakdowns during the field operation result in expensive delays and often loss of valuable test data.

If the water supply must be pumped into the storage tank from a stream, lake, reservoir, or other source, the amount and longevity of the suction lift of a pump, that is, the vertical distance from the pump intake to the water-supply level, is an important factor.

The minimum pump and engine requirements are given in the Appendix. In general, these are:

1. that pump should be directly connected to a gasoline engine capable of continuous constant speed operation for 3 to 4 hours' duration. Power failure during experiments slows down operation and usually introduces a slight error in the test run.

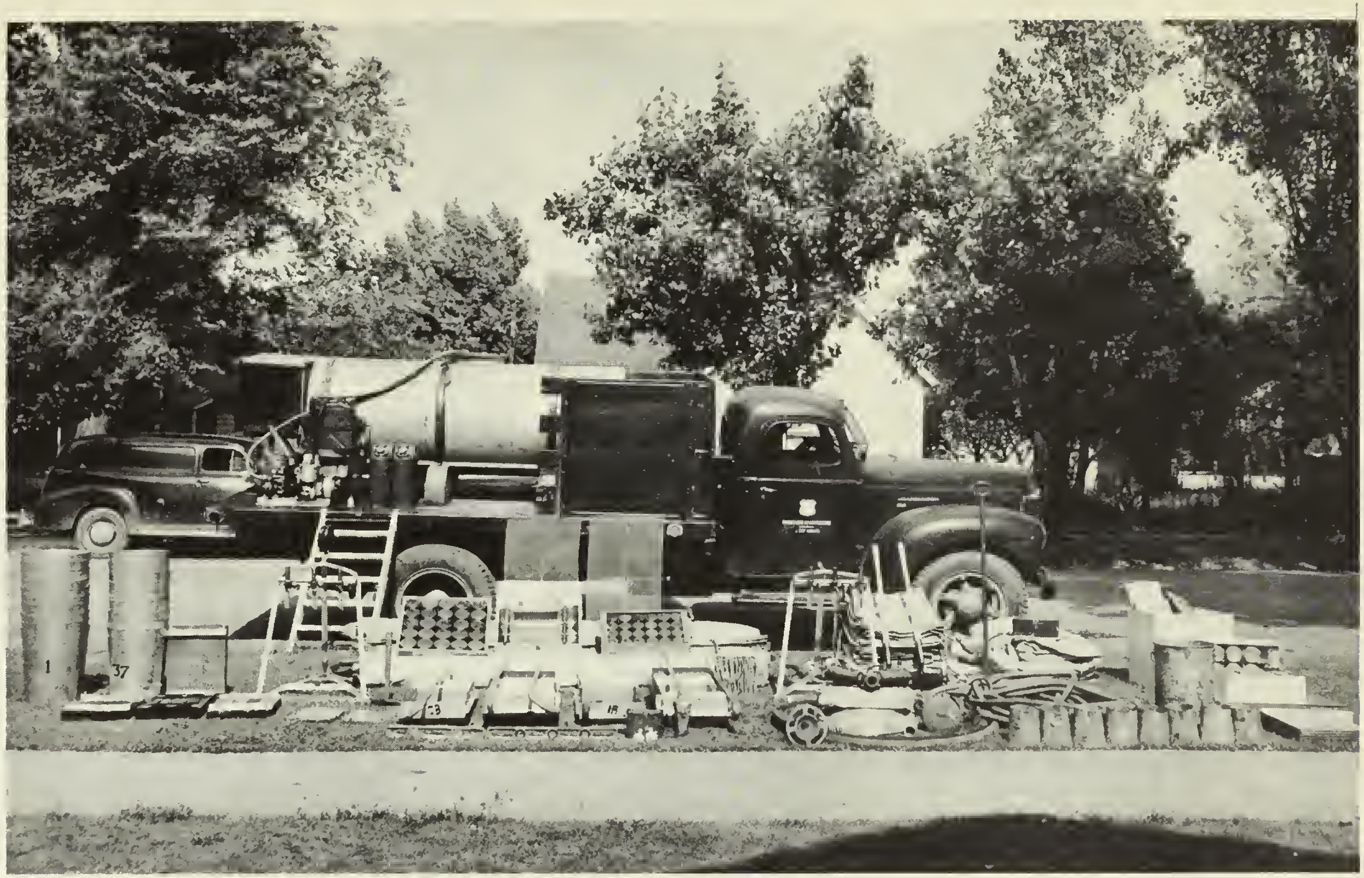

Figure 1.—Rocky Mountain infiltrometer and accessory equipment needed for infiltration and erosion tests. All apparatus can be neatly stacked on $1\frac{1}{2}$-ton truck. Note water tank support and provided storage space under tank for plot frames and rain troughs.

2. that pump should have a minimum capacity of 8 gallons per minute at 75 pounds pressure. Actual pump demand during test runs approximates 3 gallons per minute at about 25 pounds pressure at each nozzle. The additional margin is essential for normal operation but may prove inadequate when there is excess leakage in circulation system and when water is pumped uphill for considerable distances.

There are three types of pumps suitable for infiltration studies: (1) rotary; (2) centrifugal; and (3) piston. Rotary pumps have two very closely meshed rotors, gears, or impellers which revolve at high speed and through which the water is drawn by suction. Horizontal centrifugal pumps have an impeller which rotates at high speeds inside a metal housing and forces water through a discharge pipe. This type does not create a vacuum and will not draw water until pump housing and intake hose have been completely filled with water and motion has been set up in the water train. The better type piston pump has two double-acting pistons which oscillate and work on the principle of air displacement or suction.

Capacity and maximum pressure developed by these pumps will vary considerably according to their size, speed of operation, and mechanical design. Small, light-weight pumps capable of developing high pressures are necessary because plots may often lie over 150 feet in elevation above the water source. As 1 pound of pressure equals 2.3 feet of head, a pressure of at least 65 pounds is needed to push water up only 150 feet in elevation. With high-pressure pumps the nozzle pressure is cut down to between 20 and 30 pounds by using a cut-off or relief valve in the main hose line and by-passing surplus water back into the storage tank. The pump speed can also be regulated to cut down pressure at the nozzles.

Piston and rotary pumps in good working order are self-priming, because they operate on the vacuum principle and will start pumping water almost as soon as the engine is started. Centrifugal pumps, on the other hand, must be primed by completely filling the pump housing and intake hose with water before the engine is started.

Centrifugal and piston pumps have effective suction lifts of about 22 feet at sea level.[3] Rotary pumps seldom have continuous effective suction lifts of over 16 feet at sea level. The guaranteed length of life of maximum specified suction lift is an important factor. All pumps work more effectively and yield higher flows when within 10 feet of the water surface.

The rotary pump, because of its mechanical design, is unable to handle sand or grit. Its efficiency and effective suction lift are dependent solely upon having a close fit between the rotors (gears) and housing in which they operate. When sand or grit passes through them, the very close fitting becomes worn and suction ability is reduced or entirely destroyed. Clear water should be used at all times, since any sand or grit will also plug the rainfall nozzles. The suction lift can be effectively increased temporarily by pouring heavy oil into the rotor housing. However, according to the writer's experience, rotary pumps may not be desirable where maximum suction lifts must be maintained, as gears may need replacement after only 200 hours of operation.

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[3] Effective suction lifts will be reduced with any appreciable increase in elevation. The height of a water column in a vacuum at sea level and 50° F. is 33.9 feet, but is reduced to 23.4 feet at 10,000 feet elevation. In the field it is usually found difficult to maintain a column of water more than 65 percent of the theoretical amount so that the effective suction lift at 10,000 feet elevation approximates 15 feet.

Types of pumps and engines recommended

Pacific Marine Portable Type "Y" Pumper
(Pacific Marine Supply Co., Seattle, Wash.)

This pump has been used with our equipment during two field seasons and has proved satisfactory. The two main objections are that most infiltration studies generally utilize less than 25 percent of the pumped water, necessitating by-passing the excess amount into the storage tank. Yet, this extra margin is often essential when additional pressure is needed for pushing water uphill at great distances.

The second, more important objection is that we found this pumper would not lift water more than a few feet at 8,000 to 10,000 feet elevation when gears became worn after about 200 hours of operation.[4] Pump repair or replacement was found necessary to maintain high suction lifts. Unless these maximum lifts must be maintained, wear in gears does not become a problem. The pumper is entirely suitable for pushing a stream of water after considerable use and wear.

The dimensions, costs, and motor specifications are given in the Appendix.

Necessary modification of Pacific Marine type "Y" pump for infiltration tests

The present design of the Pacific Marine type "Y" pumper discharges the "coolant" water and exhaust fumes from the same outlet. When hauling water to sites to be tested it is essential that all water be conserved. The discharged "coolant" water, if wasted, would empty the storage tank before completion of a single run.

Since it is essential that exhaust fumes are not discharged into the storage tank because of their contaminating effect, these must be separated from the "coolant" water. The revised cooling system is shown in figure 2.

The method used is described:

> Remove copper tubing, brass elbow, and straight connector used in by-passing "coolant" water from engine to exhaust manifold elbow. Braze a 3-inch length of 1/2-inch standard brass tubing to one end of the brass straight connector. Insert the other

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[4] A new pump has performed better. After about 150 hours of operation this pumper fills the 425-gallon tank in 10 minutes of pumping under a 10-foot lift at 10,000 feet elevation.

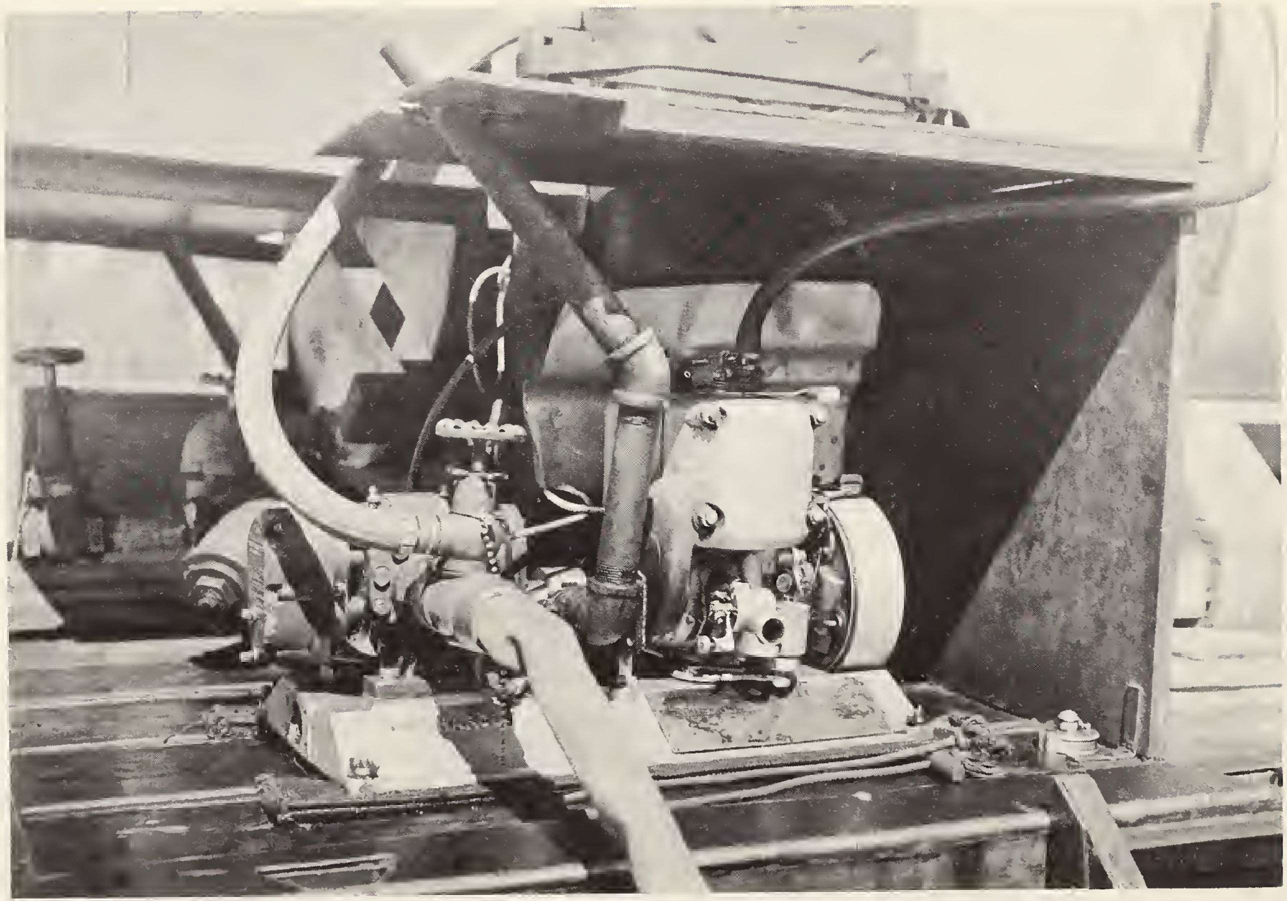

Figure 2.—Close-up view of Pacific Marine pump mounted on bed of $1\frac{1}{2}$-ton truck. The 3/4-inch hose on the left by-passes excess discharged water into storage tank. The auto heater hose on right returns "coolant" water to tank. Note specially constructed exhaust made of 1-inch galvanized pipe and sheet metal "safety" shield that keeps any gasoline leakage from striking engine.

end of this connector into the hole left in the top of the engine by removal of the brass elbow. Attach one end of a 12-foot section of 5/8-inch (inside diameter) standard automobile rubber heater hose to the 3-inch brass tube by means of a worm-gear clamp and place the other end in the water storage tank. Insert a metal plug in the hole left in the exhaust manifold elbow after removal of the straight connector. Remove the exhaust manifold elbow and weld a 90°-1" pipe elbow to the end previously attached to the engine. Attach this altered manifold elbow to the engine in reverse position. A small amount of metal trimming will be necessary in fitting the base end to the engine. Attach about a 15-inch length of 1-inch galvanized iron pipe to the 90° pipe elbow so that exhaust fumes (contain waste oil) are sent skyward and clear of operators and equipment.5/ Dry exhaust gases must be diverted into space and not allowed to pass through the base as it would become warped from excess heat. The only undesirable effect is a slightly increased noise level.

Pacific Marine Portable Type "5-A" series
(Pacific Marine Supply Co., Seattle, Washington)

The new types 5-A-5, 5-A-7, and 5-A-8 pump units now manufactured by Pacific Marine Supply may be suitable for infiltrometer tests, but have not been tested. This pumper is similar to the type "Y" although quite a bit smaller, weighing only 38 pounds. It is powered by a 2-cylinder, 2-cycle, alternate firing unit. An important feature of this pumper is that the cooling water is automatically returned to the suction side of the pumper, thus forestalling water loss.

It is probable that the 5-A-5 unit will prove adequate for most infiltration tests, although a considerably longer period of time will be needed for filling the tank.

Centrifugal Pumps

A Jaeger Portable centrifugal pump capable of producing 35 pounds pressure was used by the Flood Control Survey with the type F infiltrometer. Wilm et al (22) used this pump with the modified FA (Rocky Mountain) infiltrometer for laboratory tests conducted at Fort Collins in 1942. In this study a 15-pound pressure was maintained at each applicator. Although this pump proved adequate for laboratory studies, a more powerful unit capable of producing higher pressures is recommended.

Recently Leatham and Riesbol (8) have recommended the use of a three-stage centrifugal pump for maintaining a steady 34-pound operating pressure with the type F (20,21) infiltrometer. They found that a single stage pump failed to maintain a steady pressure.

5/ An improvement might be to use a 45° pipe elbow, reverse direction, and place the 1-inch pipe through the bed of the truck.

TRUCK AND STORAGE TANK

The minimum size truck needed is 1½ ton, with dimensions of bed approximately 8 x 12 feet. This size is necessary to provide ample storage space for all equipment in addition to the water tank. Dual wheels are needed and four-wheel drive is preferable.

The tank should have a capacity between 400 and 500 gallons. With a 425-gallon tankful of water and all equipment, the weight approximates 6 tons; 3 tons being the tare weight of the truck. This is well within the limit of the 8-ton capacity of this type of truck. Under normal operation the tank must be filled twice a day. In order to operate one full day on a single filling, the tank capacity would need to be increased to over 800 gallons. If this size tank is used, a heavier and larger truck or trailer is needed, and maneuverability must be sacrificed. With a 1½-ton truck, sampling dense stands of ponderosa pine and pinyon-juniper types was possible. Unless sources of water supply are considerably distant, it is quite doubtful that a heavier truck and larger tank would be more economical in over-all cost and operation.

In figure 1 all of the equipment is shown stacked on the ground. This same equipment is shown in figure 3 neatly stacked on the 1½-ton truck. A similar arrangement is recommended for ease in handling and for maximum speed of operation.

PORTABLE METAL PLOT FRAMES, RAINFALL TROUGHS, AND RAIN APPLICATORS

Plot Frames

The infiltrometer plot frame measures 12 x 30½ inches in plan dimensions, and is 6 inches deep with 3 inches to be set below the soil surface and 3 inches above (fig. 4). The area of this plot frame is so designed that 1 inch depth of water equals 6,000 cubic centimeters. This convenient conversion factor simplifies calculations and is particularly helpful during calibration and field operation for rapid checking. The plot frame has a trough at the lower end for collection of surface runoff and soil erosion. A fly screen trash collector (fig. 4) is placed over the collector trough during the field test to prevent organic matter and vegetation from clogging the runoff in the drain system. The runoff water passes through 2 feet of 3/4-inch rubber garden hose and 5 feet of 1/2-inch drain pipe and is collected in 1-gallon containers.[6] Runoff is measured volumetrically in lucite cylinders[7] graduated in cubic centimeters and later converted to inches per hour. On gentle slopes 1 cubic centimeter of runoff per minute equals 0.01 inch per hour. The 1/2-inch drain pipe is connected to the plot frame by the rubber garden hose. This section of rubber hose provides flexibility needed during test runs, as well as when carrying frames or transporting them on the truck (fig. 1 and 5).

6/ No. 10 food cans.

7/ Method of preparing and cost of lucite cylinders may be obtained from E. L. Hamilton, California Forest and Range Experiment Station, Glendora, California.

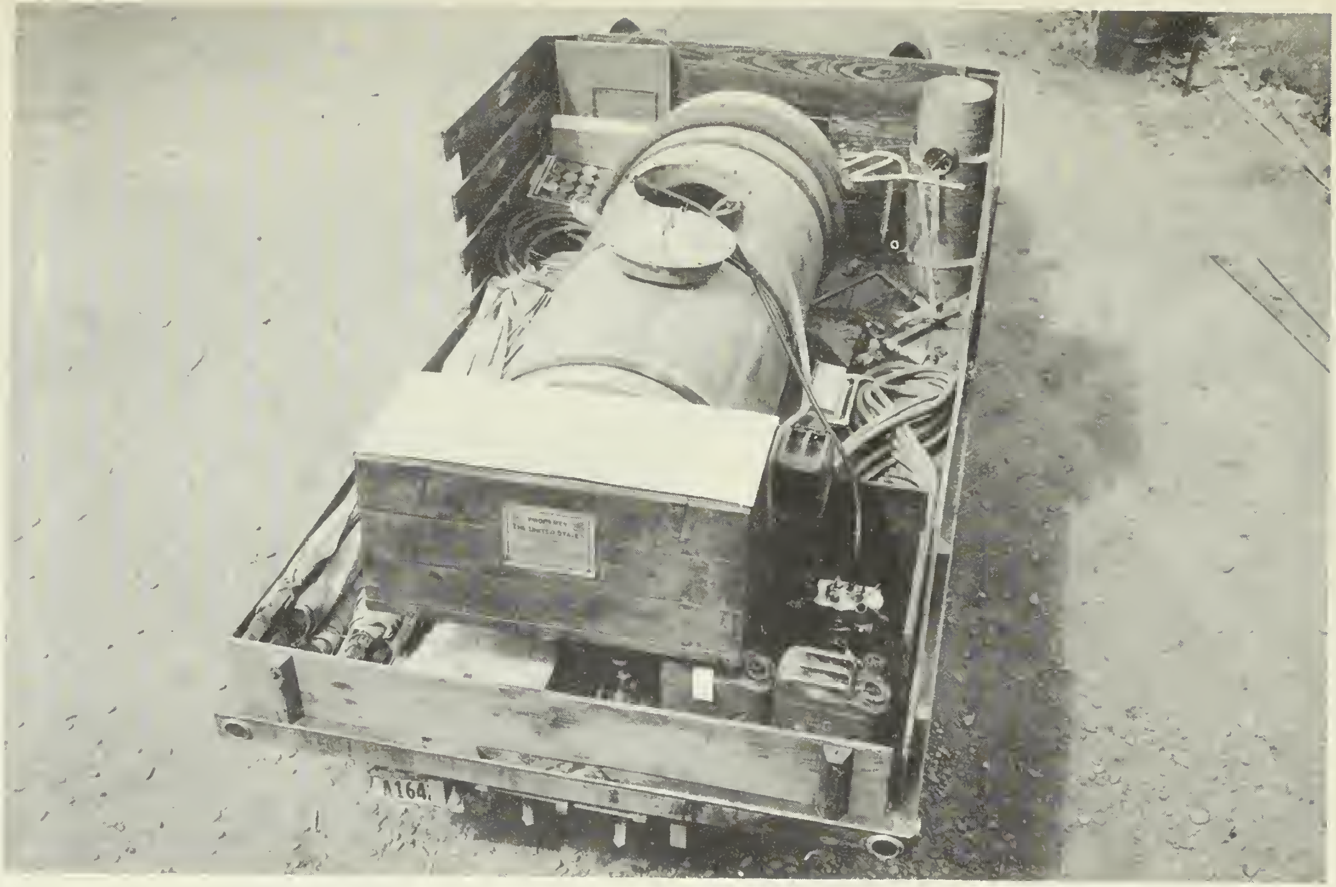

Figure 3.—Infiltrometer equipment neatly stacked on $1\frac{1}{2}$-ton truck. Note runoff troughs and frames stored under tank, rainfall applicators in front of tank, and low sideboards used in short hauls. Siamese coupling and attached 50-foot sections of 3/4-inch hose stored to right of tank, other 3/4-inch hose, $1\frac{1}{2}$-inch canvas hose, and windbreaker tents to the left of tank. Note stepladder strapped under truck bed.

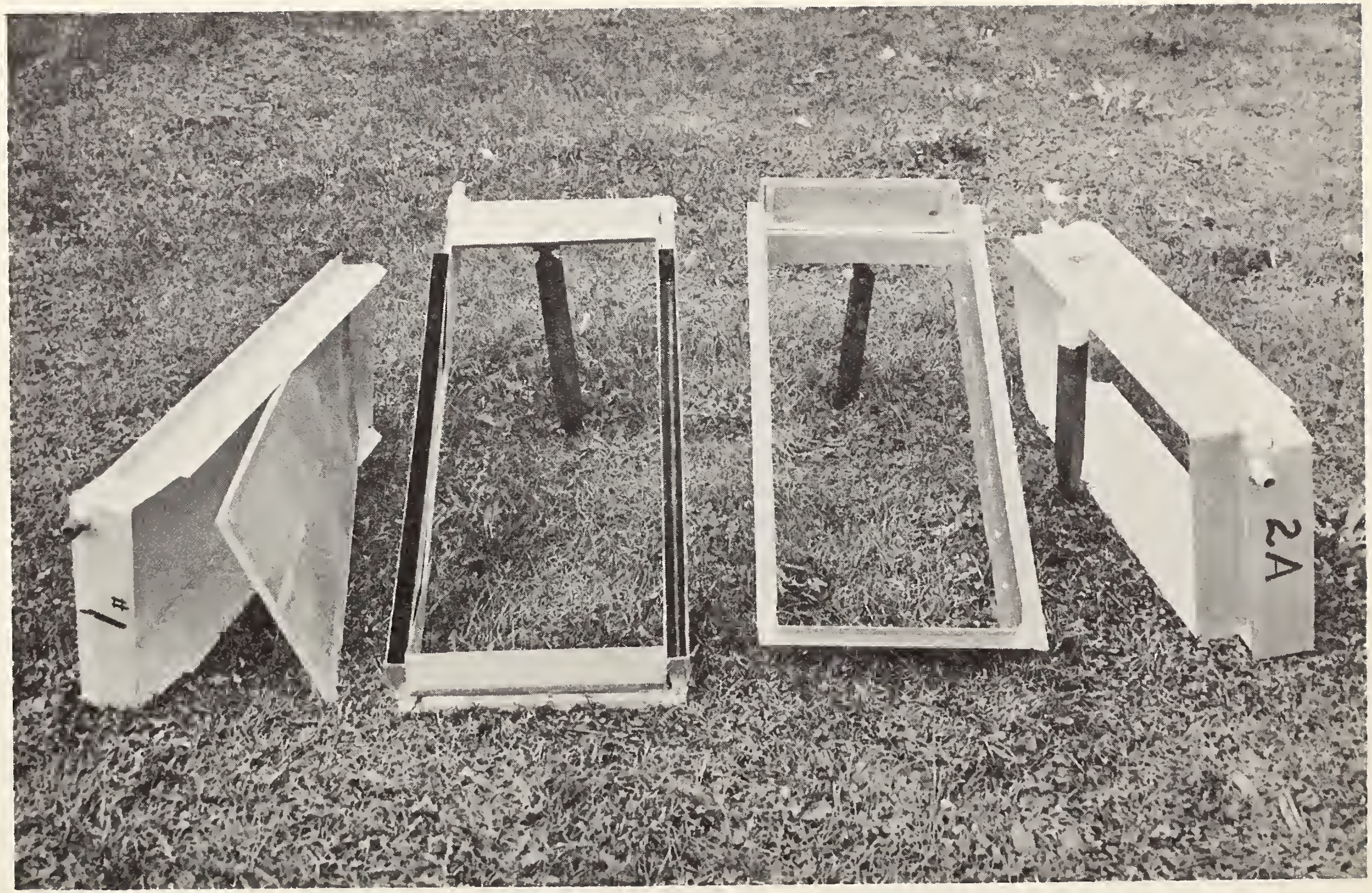

Figure 4.—Close-up of rain pan with splash screen, rain troughs, plot frame with trash screen in place and side view of plot frame in order named from left to right. Metal tent stakes are used for supporting the various items.

Rain Troughs

The dimensions of the rain trough gages are 1 x 30½ inches and 3 inches deep. They are mounted with their inside edges ¼ inch away from the plot frame. One trough is mounted on each side of the plot frame and is held together by an angle iron frame so that the whole unit may slide up or down on the plot frame to a position varying with the slope of the plot. On a steep slope[8] it is moved as far uphill as possible, while on level ground it is pushed as far as possible in the opposite direction. The rain trough frame delimits the plot length, allows rain to strike the plot area on any slope and prevents water from dropping directly into the collector trough. Runoff water from each trough drains into a ½-inch pipe system coupled together by means of a 2-foot section of 3/4-inch rubber garden hose in a similar hookup used for plot frames (fig. 5). Runoff water is collected in 1-gallon cans and measured volumetrically in a lucite graduate. Since the troughs delimit only one-sixth of the area of the plot frame, 1 cubic centimeter of runoff per minute equals 0.06 inch per hour on gentle slopes.

Rainfall applicator

Three type F nozzles are attached to a 3/4-inch pipeline system that is permanently mounted on an angle iron frame (fig. 5). The frame has two 3½-inch extensions projecting from the triangular base. These extensions fit against the rain troughs, setting on the angle iron extension of the plot frame. In this way the nozzles are always placed parallel to the plot and about 4 inches from it. When the base of the frame is leveled from the plot outward[9] (looking upslope) the angle of the nozzles is 4 degrees from vertical toward the plot. This arrangement centers the plot in the rainfall pattern. Each nozzle is mounted in a street-elbow so that it can be rotated in a plane parallel to the long axis of the plot. This allows the nozzles to be plumbed[10] or set in a vertical position on plots of any slope (fig. 5). In this way each nozzle throws its spray upward in a plane parallel to the short axis of the plot and at a 4-degree angle in the other plane. The three nozzles are spaced 5.3 inches apart on the applicator pipe. A pressure gage of 0 - 30 pound capacity, and sensitive to ¼ pound is connected to the 3/4-inch applicator pipe near the open end away from the nozzles. A 3/4-inch pipe to hose coupling is fitted at this open end. The pipe end and gage are fitted through the slit in the wall of the windbreaker tent. The best type pressure gage available should be purchased. Even with the best type gage, fluctuations in rainfall intensity occur when pressures are held constant according to gages.

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[8] Maximum slope that can be tested with this equipment is 50 percent. If steeper slopes must be sampled the equipment should be altered. Rain-trough frames should be lengthened and applicator frame revised to prevent upsetting.

[9] Frame is leveled parallel with surface plane of plot by placement of metal carpenter's level in guides notched in angle iron comprising the base of the frame (fig. 5).

[10] A suggested improvement to facilitate plumbing nozzles is to provide a ball and socket joint.

The type F nozzle consists of an alternating series of disks and sleeves enclosed and confined to definite positions by a cylindrical shell, which in turn is screwed into a threaded base. The base is designed for mounting on standard pipe fittings and acts as a housing for an entrance arrangement composed of a helix mounted rigidly within an entrance tube. It is necessary that holes in disks be correct in size, be exactly in the center, have square edges, and be perpendicular to the plane of the disks. In addition, disks should be perfectly flat and close fitting to the cylinder walls. Spacer sleeves must be cut at right angles to their longitudinal axes. High class machine work is essential in construction of these nozzles.

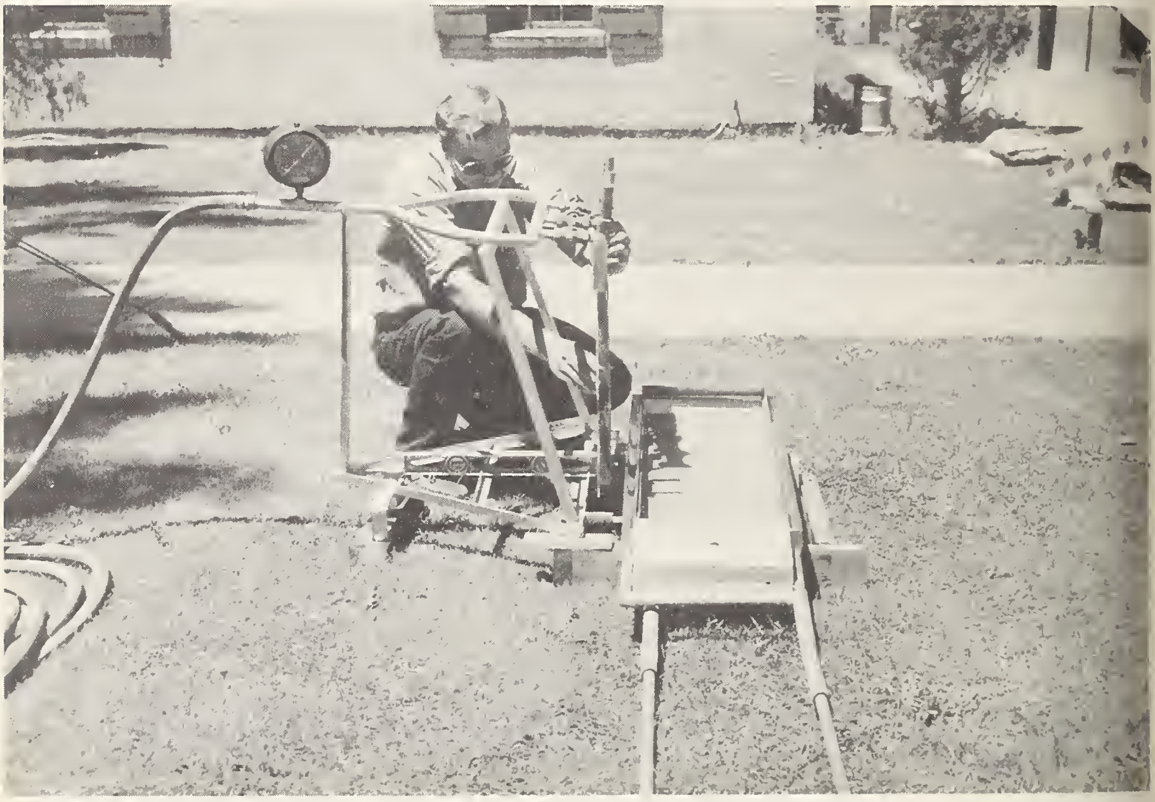

Figure 5.--Close-up view of rainfall applicator, rain pan with splash screen inserted, and rain troughs. Note 2-foot garden hose connection to runoff pipes, pressure gage, spirit level, beaded chain and support for applicator and rain pan. Slope is 20 percent. Operator is plumbing nozzles.

The circulating system from mounted tank to pump comprises two $1\frac{1}{2}$-inch 90-degree street-elbows; five $1\frac{1}{2}$-inch close pipe nipples; one $1\frac{1}{2}$-inch long pipe nipple; one $1\frac{1}{2}$-inch union; one $1\frac{1}{2}$-inch tee; one $1\frac{1}{2}$-inch pipe strainer; two $1\frac{1}{2}$-inch gate valves; about 6 inches of 1-3/4-inch rubber radiator hose with wire spring and clamps; and one $1\frac{1}{2}$-inch female hose coupling (fig. 6). All pipe fittings should be galvanized to prevent rust from forming.

The inclusion of a Fre-Flow strainer in front of the pump intake is particularly important when using a rotary pump. This should insure a longer life, as any extraneous solid material passing through the suction hose or out of the tank will be intercepted before reaching the pump. The $1\frac{1}{2}$-inch brass female hose coupling is secured to the pipe nipple on the pump intake with a spanner wrench. This simplifies the hookup for assembling and disassembling. The pump can be easily removed from the truck for placement near a water source not accessible with the truck. Occasionally, water must be lifted into the tank more than the 15 or 20 feet possible by suction. The Pacific Marine pump will push a stream of water through a vertical distance of about 500 feet.

It is necessary to weld a 2-inch length of $1\frac{1}{2}$-inch galvanized iron pipe to one end of the female coupling to provide a means for clamping the rubber hose. A wire spring should be inserted in the rubber hose to prevent its collapse when drawing water by suction. An extra machined X-37 Pacific Marine Supply nipple is needed for attachment to the open end of the $1\frac{1}{2}$-inch gate valve to provide a means for coupling the suction hose for normal pumping operations.

The system from pump to applicators consists of: one pressure relief valve; one or more sections of $1\frac{1}{2}$-inch pacolized linen forestry fire hose with aluminum couplings; one unit siamese valve; two $1\frac{1}{2}$-inch to 3/4-inch reducers; two 3/4-inch pipe strainers; two 3/4-inch globe needlepoint valves; and 3/4-inch rubber hose, in the order named (fig. 7).

The pressure relief valve provides a means for by-passing excess discharged water from the pump. It is supplied with a 1-inch takeoff on the discharge side to which is attached a 12-foot length of either 1-inch or 3/4-inch rubber garden hose. Excess discharged water is returned to the storage tank through this system. "Pacolized" linen forestry hose should be used because of the lightness in weight and increased flexibility. Pacolized linen hose is only one-third the bulk of ordinary cotton rubber-lined hose. Aluminum couplings are lighter than brass and fully as satisfactory. The unit siamese valve (inverted plug pattern) releases water through either outlet or both and permits shutting off of either one or both as required. It is light weight, compact, and withstands 250 pounds of working pressure. Pipe strainers are designed to remove all dirt, scale, or other foreign material, yet pass hose line capacity at a small pressure loss. Self-cleaning feature permits

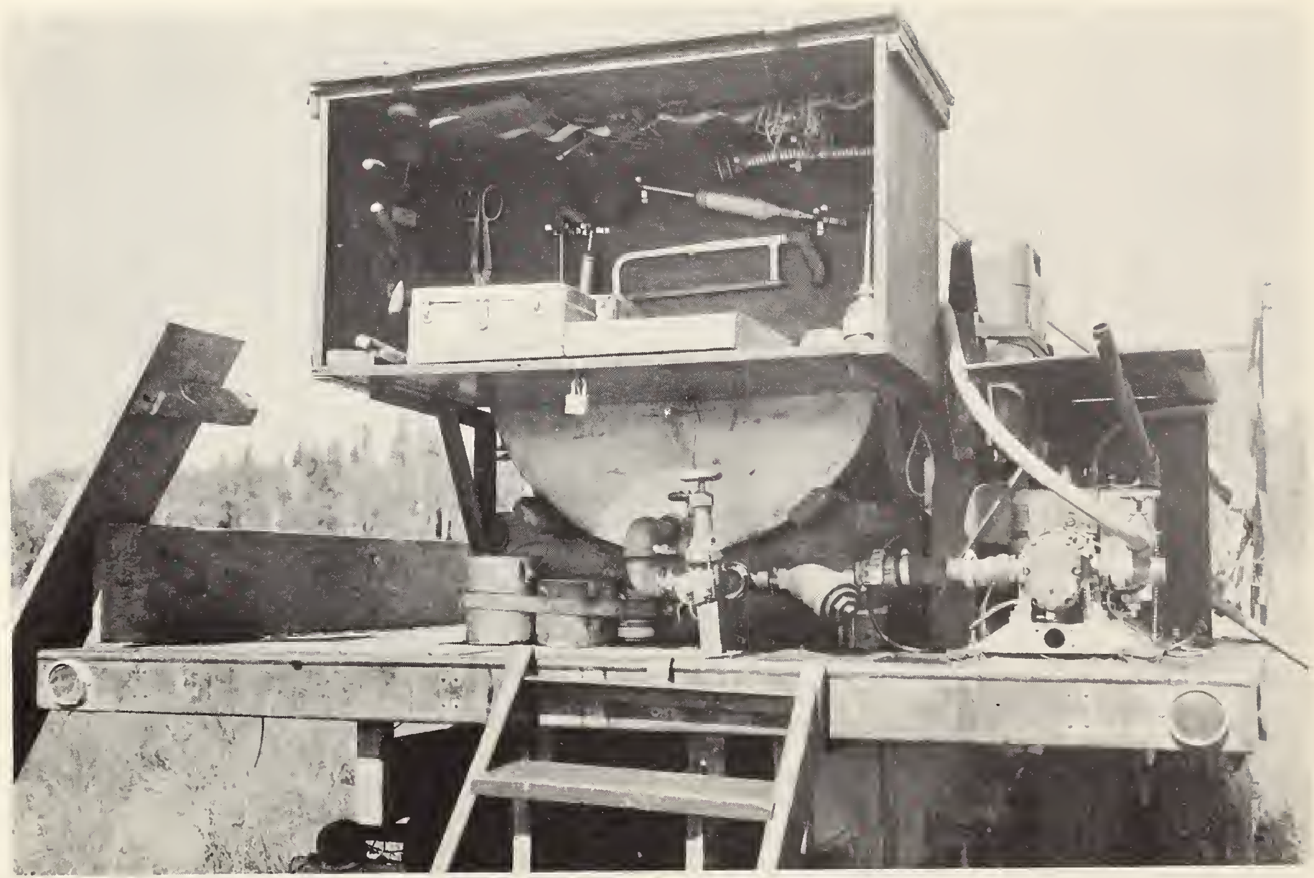

Figure 6.—General rear view of $1\frac{1}{2}$-ton truck showing circulation system, pump, tank, ladder, and tool box. Note elevated position of tank above truck bed, design of ladder which allows placement at rear or side (fig. 7), and metal angle iron braces that support the tool box.

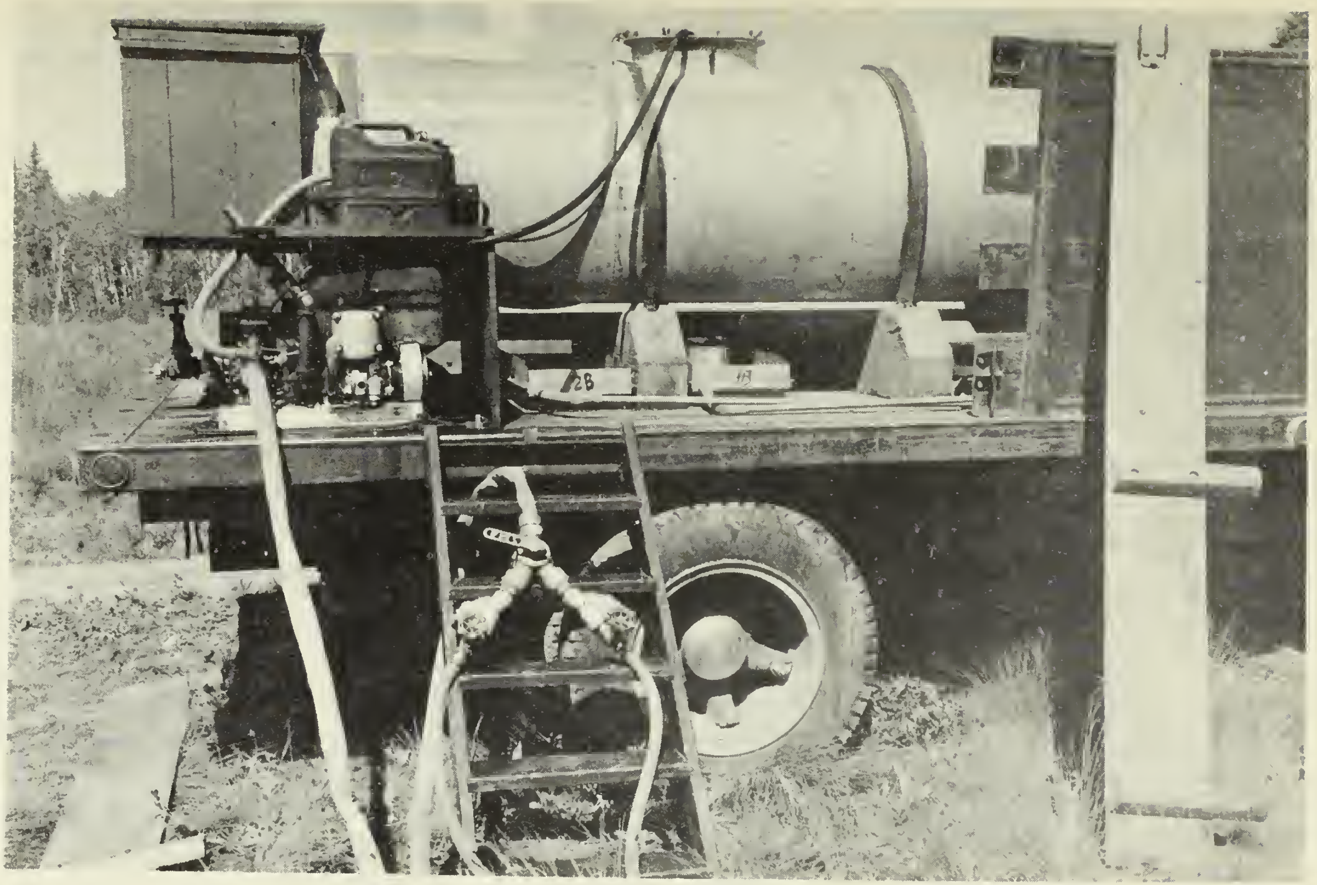

Figure 7.—Side view of $1\frac{1}{2}$-ton truck showing water circulation system from Pacific Marine pumper Note 3/4-inch by-pass and 5/8-inch "coolant" water hoses fastened with clamps to man hole bolts. Siamese is coupled to two $1\frac{1}{2}$-inch to 3/4-inch pipe reducers, two pipe strainers, and two needle valves.

cleansing screen by simply opening blow-off valve. The 3/4-inch globe needlepoint valves are used for accurate adjustment of pressures at the nozzles. There is no need for a surge tank with this system, even when the minimum 50 feet of 1½-inch hose and two 50-foot sections of 3/4-inch rubber hose are employed. With a pressure of about 40 to 50 pounds in the main hose and 20 to 30 pounds at the nozzles, the hose system serves as an adequate surge tank.

A 25- to 50-foot length of suction hose should be equipped with a suction strainer so as to prevent pumping sand, gravel, or other foreign matter. This strainer should always be used on the intake end of the suction hose even though the system is provided with a pipe strainer on the pump intake side.

CALIBRATION EQUIPMENT

Rain Cans

Rain cans are used in the preliminary pattern tests for selection of nozzles and pressures needed for uniform rainfall distribution and correct intensity. Approximately 30 cylindrical cans[11] are used for testing each rainfall applicator. These can be constructed of seamless brass tubing and should preferably measure 0.992 inch in diameter and be 4 inches deep to prevent any splash loss. This diameter provides the easy conversion factor---1 cubic centimeter of water equals 0.01 inch depth of water. Rainfall volume is measured in the lucite cylinders.

Rain cans are set in wooden frames and placed over the central area covered by each sprinkler (fig. 8). Each frame holds 32 rain cans. The top of rain cans should be placed 30 inches from the nozzle orifices, or the same distance as the rain cutting edges of plot frames and rain troughs.

Rainfall Pans

Rainfall pans measure 12 x 33 inches in area and are 3 inches deep. The pans are similar to the plot frames with the sole exception that a metal bottom is placed in the rain pan for collection of all rainfall striking the area. Also, the 3 inches of metal side-wall of the plot frame that is driven into the soil is omitted from rain pans. A screen made of 14-mesh galvanized wire and spread ½ inch above the floor of the rain pan is used to prevent any loss in rainfall through splashing (figs. 4, 5, 9).

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[11] Frozen fruit juice cans may be used, provided 14-mesh wire screen is placed in each can to prevent splash loss and between cans to prevent rain splash from entering them.

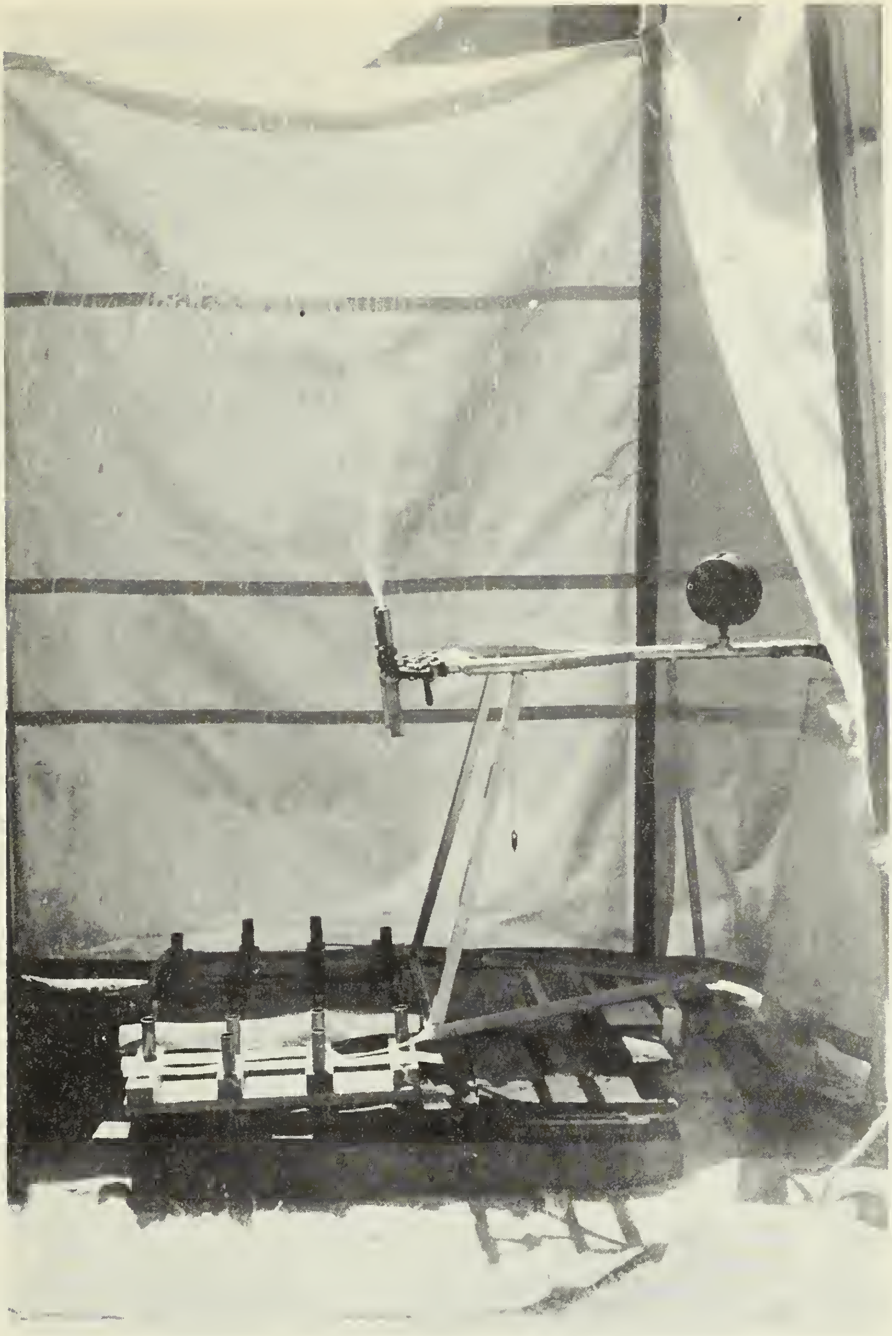

Figure 8.—Rainfall pattern during calibration test. One-inch rain cans determine rainfall distribution. Pressure gage reading, 22 pounds; maximum height of drops, 7 feet; intensity, about 5 inches per hour. Wire screen placed between cans to minimize splash

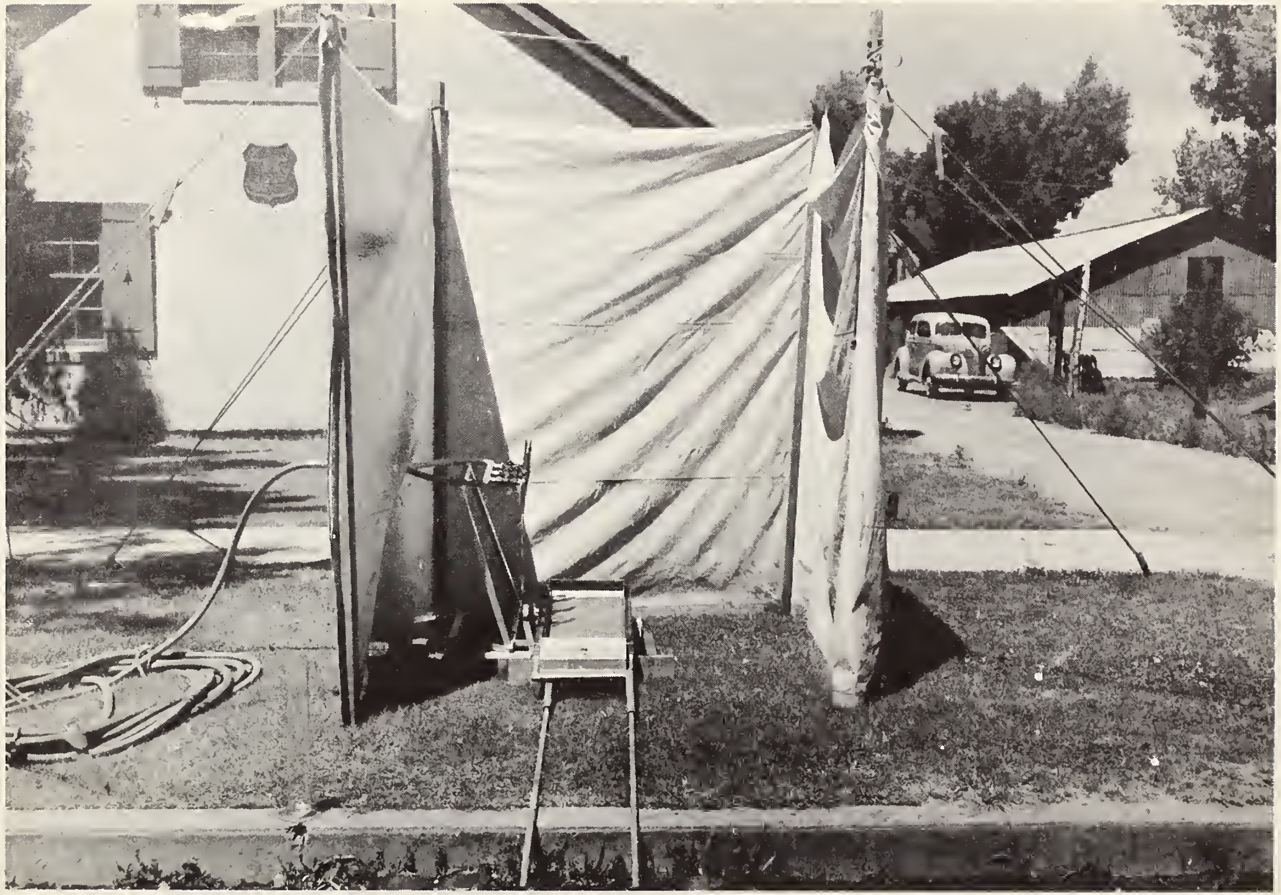

Figure 9.—View of rainfall applicator, rain pan, and troughs during a calibration test run. Runoff pipes are placed over 1-gallon collector cans.

CALIBRATION OF INSTRUMENT

Infiltrometer should be carefully calibrated prior to its use each season. The calibration should also be checked during the field season whenever any apparent change in instrument performance occurs. It is preferable to conduct calibration tests indoors, if suitable space is available. All that is necessary is ample concrete floor space provided with a floor drain. The entire area should be well protected from air disturbances. Calibration tests can be conducted satisfactorily outdoors, if suitable indoor space is not available. It is, however, necessary to install windbreaker tents as in field tests of soil infiltration and erosion rates. The writer has satisfactorily calibrated infiltrometers outdoors since 1946, as suitable indoor space was never available.

The calibration consists of three steps:

1. Measurement of areas of all rainfall intercepting equipment;
2. Trial-and-error procedure used in establishing a uniform distribution pattern of desired intensity by interchanging nozzles, nozzle parts, and by slightly varying pressures.
3. Establishment of a correction factor for gross rainfall caught in the rain-gage troughs.

The first step in calibration requires accurate measurement of areas of all rain-intercepting equipment since they are seldom constructed to exact specifications. Moreover, plot frames and rain troughs are altered slightly during field use regardless of care in handling. This equipment should be measured both at the beginning and end of the field study and items repaired and straightened with an attempt at approaching original dimensions. In our studies these areas have never varied more than one-half percent during an entire field season.

About 15 caliper measurements of widths of plot frames, pans, and troughs; 2 measurements of lengths of troughs; and about 6 measurements of rain pan and plot frame lengths will suffice. The lengths of rain pans and plot frames are controlled by the distance between the rainfall cutting edges of cross-members connecting the two rain troughs.

During the next part of the calibration, a network of small rain gages is used to establish a uniform distribution of rainfall over a circular area of about 3 feet in diameter. The entire wetted area approximates 7 feet in diameter to prevent lateral movement of water during field tests, but only the central portion of this zone is occupied by the plot frame and troughs. An even distribution of 50 small rain gages supported by a wood frame (20 x 40 inches) is placed near each applicator so as to cover the central portion of the rainfall pattern. The entire assembly of rainfall applicator and rain gages should be set on a plane similar to the approximate average slope to be encountered during field tests. In our studies this has varied from 10 to 20 percent. Even when variation in slopes to be sampled is considerable, it is doubtful that separate correction factors are needed. In laboratory tests, Wilm et al (22) concluded that rainfall volume and pattern are regulated with satisfactory accuracy on differential slopes and at different rates of artificial rainfall. Our field calibrations have substantiated these conclusions. Expected variation in rainfall intercepted by the plot frame and rain troughs for various slopes are presented under correction factors. Nozzles should be placed 30 inches above the tops of rain gages; that is, the same distance as between nozzles and rainfall cutting edges of rain troughs and plot frames. The rain pattern should center over the plot position as indicated in table 1.

Normal working pressures at nozzles should vary between 20 and 30 pounds, or that necessary to maintain a 7-foot height of raindrops. This minimum height is desirable to approximate the terminal velocity of falling rain (1), and it is not practical to make windbreak tents higher than 7 feet. The type F nozzles were originally designed for an operating pressure of 35 pounds per square inch[12a/], but a lower pressure is necessary to prevent drops from exceeding the 7-foot height. The writer found only small fluctuations in rate of application when using pressures above 20 pounds, but considerable variation when employing the 15-pound pressure originally recommended for the FA infiltrometer. Wilm et al (22) recognized the need for increasing normal working pressures but believed the height, angle, and position of nozzles would require considerable alteration with relation to the plot. A 2- or 3-degree nozzle tilt would probably result in a better centering of the pattern at these higher pressures. Yet the writer has satisfactorily calibrated two sets of applicators and four sets of nozzles with the 4-degree angle at pressures varying between 20 and 27 pounds. In practice the performance of individual nozzles varies so much that a large range of rainfall intensities may be obtained by simply interchanging nozzles or nozzle parts. Some idea of this variation is given by the similarity in two rainfall patterns shown in tables 1 and 2. One was obtained with two outside nozzles and the other with three totally different nozzles. When cleaning nozzles, it is important to replace all parts in original order so as to prevent any change in performance.

In field studies we are now employing three nozzles; thus the nozzle variations tend to compensate one another and much more uniform rainfall patterns are obtained. The only advantage of using two nozzles for a required intensity is that it leaves an extra nozzle for use whenever two nozzles fail to produce rainfall excess on plots with extremely high infiltration rates.

Once the rainfall pattern of desired intensity is obtained, the last step--obtaining the correction factor--can be taken. This adjustment would not be necessary if a uniform distribution of rainfall could be obtained over the central portion of the sprinkled area, but that is practically impossible with this instrumentation. As previously shown, the pattern falls off in intensity rate from the center outward to the periphery, necessitating a 1- to 7-percent adjustment in the rainfall rates measured in trough gages. During this step the rain troughs are placed over the

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[12a/] SCS--Office of Research
November 1941--Standard procedure for operation of type "F" infiltrometer.

rainfall pan and the entire unit is set at the expected average slope (figs. 5, 9). The two applicators are run simultaneously as in the field runs. We have found that reading of pressure gages is facilitated by placing left applicator on the right hand side and right applicator on the left hand side of plot frame when viewing setup from below (tables 1 and 2), so that the two gages face each other more often, and visibility from the valve position is improved.

Table 1. Rainfall pattern during 20-minute run employing two outside nozzles (Total inches of rainfall for each gage)

UPHILL END

Applicator No. 1 position
pressure 22.5 lbs.

1.50	1.45	1.45	1.45	1.50
1.60	1.60	1.60	1.60	1.60
1.60	1.65	1.65	1.65	1.60
1.65	1.70	1.75	1.70	1.65
1.85	1.85	1.80	1.75	1.65
1.90	1.95	2.00	1.85	1.70
1.80	1.90	1.90	1.70	1.70
1.75	1.90	1.80	1.75	1.60
1.80	1.80	1.80	1.70	1.65
1.80	1.75	1.70	1.55	1.50

34"

16"

Applicator No. 2 position
pressure 20 lbs.

1.60	1.60	1.60	1.50	1.40
1.65	1.70	1.70	1.65	1.65
1.70	1.70	1.70	1.65	1.60
1.70	1.75	1.75	1.75	1.75
1.70	1.75	1.75	1.70	1.65
1.70	1.70	1.70	1.75	1.50
1.75	1.90	1.75	1.70	1.50
1.75	1.85	1.75	1.65	1.50
1.65	1.65	1.65	1.50	1.40
1.60	1.45	1.55	1.40	1.40

34"

16"

DOWNHILL END

Plot border including rain troughs = – – – – –

Slope = 10% (expected average of field slopes tested)

Rainfall intensity within plot area:

Applicator No. 1 = 5.3 inches per hour

Applicator No. 2 = 5.1 inches per hour

Rainfall intensity outside plot area:

Applicator No. 1 = 4.9 inches per hour

Applicator No. 2 = 4.8 inches per hour

Table 2. Rainfall pattern during 20-minute run employing three nozzles
(Total inches of rainfall for each gage)

UPHILL END

2.00	1.90	1.90	1.80	Applicator No. 1 position pressure - 20 lbs.	Applicator No. 2 position pressure - 20 lbs.	2.00	2.10	2.00	1.90	34"
2.10	1.90	1.85	1.70			2.00	2.05	1.90	1.75	
2.10	1.90	1.85	1.40			1.30	1.80	1.80	1.90	
2.00	1.85	1.65	1.55			1.40	1.70	1.75	1.75	
1.90	1.70	1.70	1.70			1.65	1.80	1.90	1.65	
2.00	1.75	1.65	1.40			1.25	1.85	1.80	1.70	
1.70	1.65	1.60	1.45			1.60	1.65	1.70	1.75	
1.65	1.60	1.40	1.40			1.60	1.50	1.60	1.65	

← 16" → ← 16" →

DOWNHILL END

Plot border including rain troughs = - - - - -

Slope = 10%

Rainfall intensity within plot areas:

Applicator No. 1 = 5.26 inches per hour

Applicator No. 2 = 5.42 inches per hour

Rainfall intensity outside plot areas:

Applicator No. 1 = 5.20 inches per hour

Applicator No. 2 = 5.11 inches per hour

The final rainfall catch obtained in the rain troughs and plot pans during a 60-minute calibration test employing three nozzles and calculated correction factors are given in table 3. The rainfall per unit area intercepted by No. 1 rain troughs was between 1 and 2 percent lower than that intercepted by the pan. The discrepance between pan and troughs for equipment 2 approached 7 percent. This represents about the maximum correction obtained in any calibration.

A check on the correction factors obtained is shown below:

Rain pattern test (using small rain gages)

$$\text{Applicator No. 1 ratio} = \frac{\text{within plot}}{\text{outside plot}} = \frac{5.26}{5.20} = 1.012$$

$$\text{Applicator No. 2 ratio} = \frac{\text{within plot}}{\text{outside plot}} = \frac{5.42}{5.11} = 1.061$$

These values compare favorably with the 1.013 and 1.069 obtained with the rain pans and troughs. The higher intensity obtained with the rain cans over that gaged with the pan and troughs is not explainable. Although pressures were held constant throughout tests, as determined by the gages, and runs were made within a few hours of each other at the same location, a difference in rate of delivery was experienced. Similar variations may be expected in the field and rainfall intensities may vary as much as 1 inch per hour between successive runs. In our field tests we now vary the pressure slightly as read by gages so as to maintain the same height (7 feet) in raindrop fall throughout the study. This automatically produces a more uniform rainfall rate. Some idea of expected variation in rainfall during field tests is given by the standard deviation of measurements made during 1948 and 1949 in Western Colorado and tabulated below:

Season	No. observations	Av. rain intensity in./hr.	Standard deviation in./hr.
1948	119	5.01	0.31
1949	116	5.22	0.37

The above deviations include numerous sites, slopes, and conditions. Moreover, they include variations due to inexperienced operators. That rainfall intensities can be kept more uniform is shown by the 0.23 value obtained for runs during the second half of the season when operators became experienced. Even with the maximum standard deviation the variation is not large, since 68 percent of all observations fell within a range of 0.6 to 0.7 inch per hour, and the maximum range was only 1.8 inches per hour. Moreover, variations in rainfall rate are greatly reduced when comparing sites or other homogeneous conditions. In 1949 the maximum range between average rainfall rates for 11 sites was only 0.38 inch per hour.

Variation in rainfall rates was partly caused by variation in slopes sampled. Yet, it is questionable whether the use of separate correction factors for differential slopes would reduce these variations. Some

Table 3. Correction factor test during 60-minute run with three nozzles

Run No.	Duration	20 lbs. Applicator No. 1 Runoff Plot pan		Ratio	20 lbs. Applicator No. 2 Runoff Plot pan		Ratio
		Plot pan	Rain trough		Plot pan	Rain trough	
	Minutes	cc.	cc.		cc.	cc.	
1	5	2445	390	6.269	2500	375	6.667
	5	2300	370	6.216	2440	370	6.594
	5	2300	375	6.133	2525	390	6.474
	5	2365	385	6.143	2475	380	6.513
	5	2375	385	6.169	2440	375	6.507
	5	2360	380	6.211	2555	390	6.551
2	5	2400	390	6.154	2525	395	6.392
	5	2435	385	6.325	2440	375	6.507
	5	2520	395	6.380	2475	380	6.513
	5	2435	385	6.325	2500	385	6.494
	5	2490	390	6.385	2510	390	6.436
	5	2495	395	6.316	2420	375	6.453
Total	60	28920	4625	6.253	29805	4580	6.508
Av.	5	2410	385	-	2485	380	-

$$\text{Correction factor} = \frac{\dfrac{\text{Pan runoff}}{\text{Trough runoff}}}{\dfrac{\text{Pan area}}{\text{Trough area}}} = \frac{\text{Runoff ratio}}{\text{Area ratio}}$$

No. 1 Applicator		No. 2 Applicator	
Pan No. 1 runoff	28,920 cc.	Pan No. 2 runoff	29,805 cc.
Trough No. 1 runoff	4,625 cc	Trough No. 2 runoff	4,580 cc.
Runoff ratio	6.253	Runoff ratio	6.508
Pan No. 1 area	365.12 sq.in.	Pan No. 2 area	369.16 sq.in.
Trough No. 1 area	59.17 sq.in.	Trough No. 2 area	60.64 sq.in.
Area ratio	6.171	Area ratio	6.088
Correction factor	1.013	Correction factor	1.069
Pan No. 1 intensity	4.86 in/hr.	Pan No. 2 intensity	4.95 in/hr.
Trough No. 1 intensity	4.79 in/hr.	Trough No. 2 intensity	4.63 in/hr.

idea of expected variation in correction factors for differential slopes may be obtained from the following tabulation:

Laboratory Calibration (22)

1 nozzle — 15 lb. pressure — 2.5 in./hr. rain intensity
2 nozzles — 15 lb. pressure — 4.5 in./hr. rain intensity

Plot slope percent	Applicator 1 1 nozzle	Applicator 2 2 nozzles
5	1.019	1.011
10	1.038	0.998
35	1.027	0.995
Field Calibration		
3 nozzles — 26 lb. pressure — 5.5 in./hr. rain intensity		
10	1.038	1.018
45	1.046	1.007

ASSEMBLING, LOADING, AND TRANSPORTING EQUIPMENT

Loading, unloading, assembling, and disassembling equipment between test runs takes up a major portion of the time of these infiltration-erosion studies. Moreover, it is an arduous task requiring considerable energy of each operator. For these reasons and for maintenance of operator morale it is essential that this phase be given careful consideration. All efforts should be directed toward simplifying and streamlining equipment and methods. Equipment should be lightened whenever and wherever possible.

Detailed drawings, photographs, and plans should help operators during these operations. The entire apparatus should be kept clean at all times and particular care should be taken to avoid denting or bending plot frames and troughs. Rainfall applicators should be handled with care and fastened solidly to truck bed during transport. Otherwise, nozzle assembly may become damaged and necessitate recalibrating equipment in midseason. The truck floor plan shown in figure 10 is designed to prevent damage to infiltrometer parts when transported over the roughest terrain negotiable by truck.

Runoff pipes are made to set over plot frame or rain trough frame by bending at hose connection (fig. 1). The entire unit slides under the water storage tank, well protected during transit. Rainfall applicators are fastened to the truck bed between water tank and rear of cab. Figures 3 and 10 show the method used.

Nested sediment cans and trays, screen grids, shovels, and axes are fastened against the truck sides up front and out of the way. Web belting with standard buckles are used to fasten down apparatus. Windbreaker tents are placed parallel to water tank and on opposite side from pump. Canvas and rubber hose, siamese assembly, and canvas covers are placed over rolled tents. The tool box is fastened to a steel frame at rear of tank and well above valves and discharge pipes (figs. 6,11). The stepladder fits under the truck bed at rear, and is fastened with web belting (fig. 11).

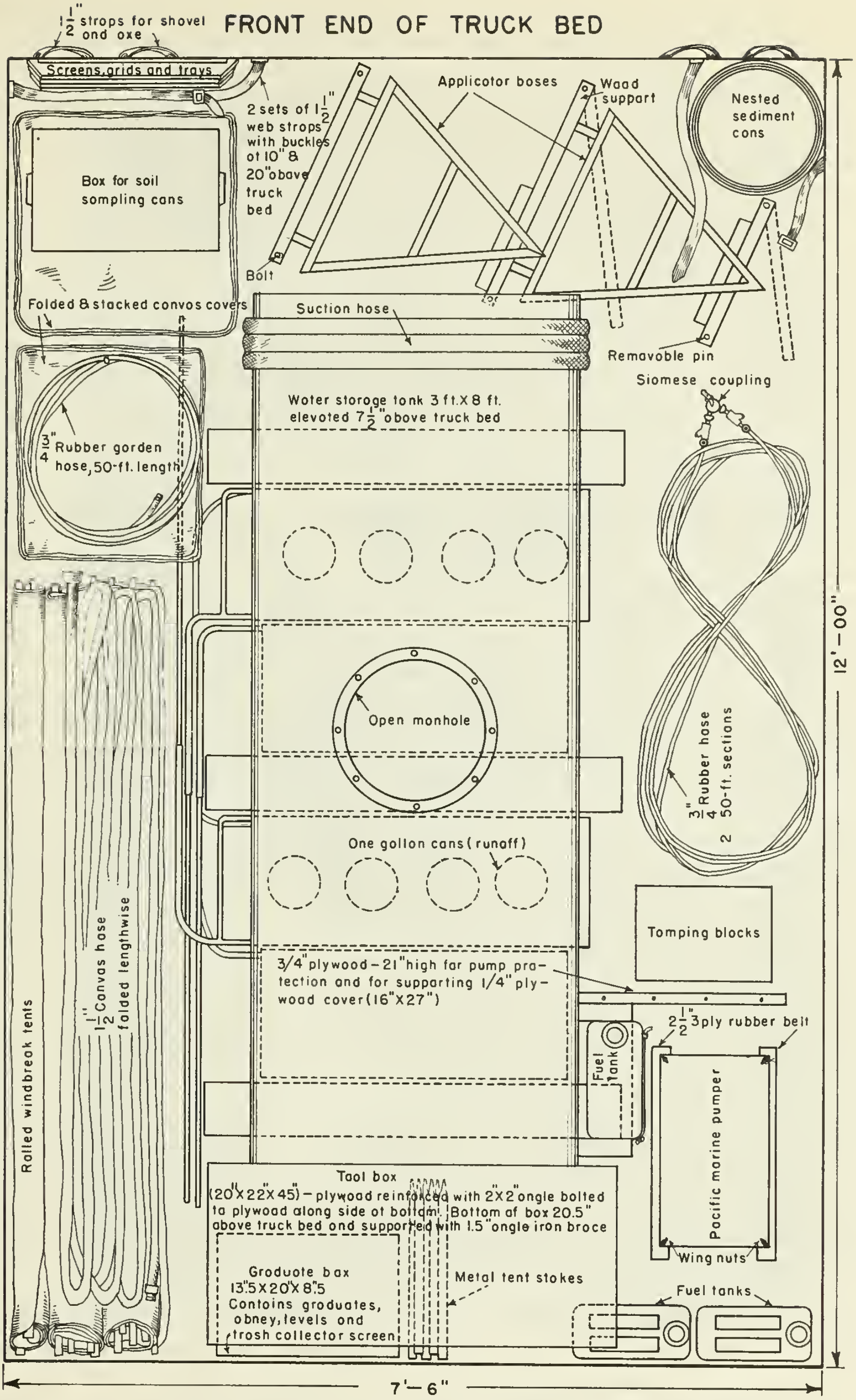
FRONT END OF TRUCK BED
1½" straps for shovel and axe
Screens, grids and trays
2 sets of 1½" web straps with buckles at 10" & 20" above truck bed
Applicator bases
Wood support
Nested sediment cans
Box for soil sampling cans
Bolt
Folded & stacked canvas covers
Suction hose
Removable pin
Siamese coupling
Water storage tank 3 ft. X 8 ft. elevated 7½" above truck bed
¾" Rubber garden hose, 50-ft. length
Open manhole
2 ¾" Rubber hose 50-ft. sections
One gallon cans (runoff)
Tamping blocks
3/4" plywood - 21" high for pump protection and for supporting 1/4" plywood cover (16"X27")
2½" 3ply rubber belt
Fuel tank
Pacific marine pumper
Wing nuts
Rolled windbreak tents
1½" Canvas hose folded lengthwise
Tool box (20"X22"X45") - plywood reinforced with 2"X2" angle bolted to plywood along side of bottom. Bottom of box 20.5" above truck bed and supported with 1.5" angle iron brace
Graduate box 13".5X20"X8".5 Contains graduates, abney, levels and trash collector screen
Metal tent stakes
Fuel tanks
12'-00"
7'-6"

FIG. 10 PLAN FOR PLACEMENT OF INFILTROMETER EQUIPMENT ON TRUCK BED

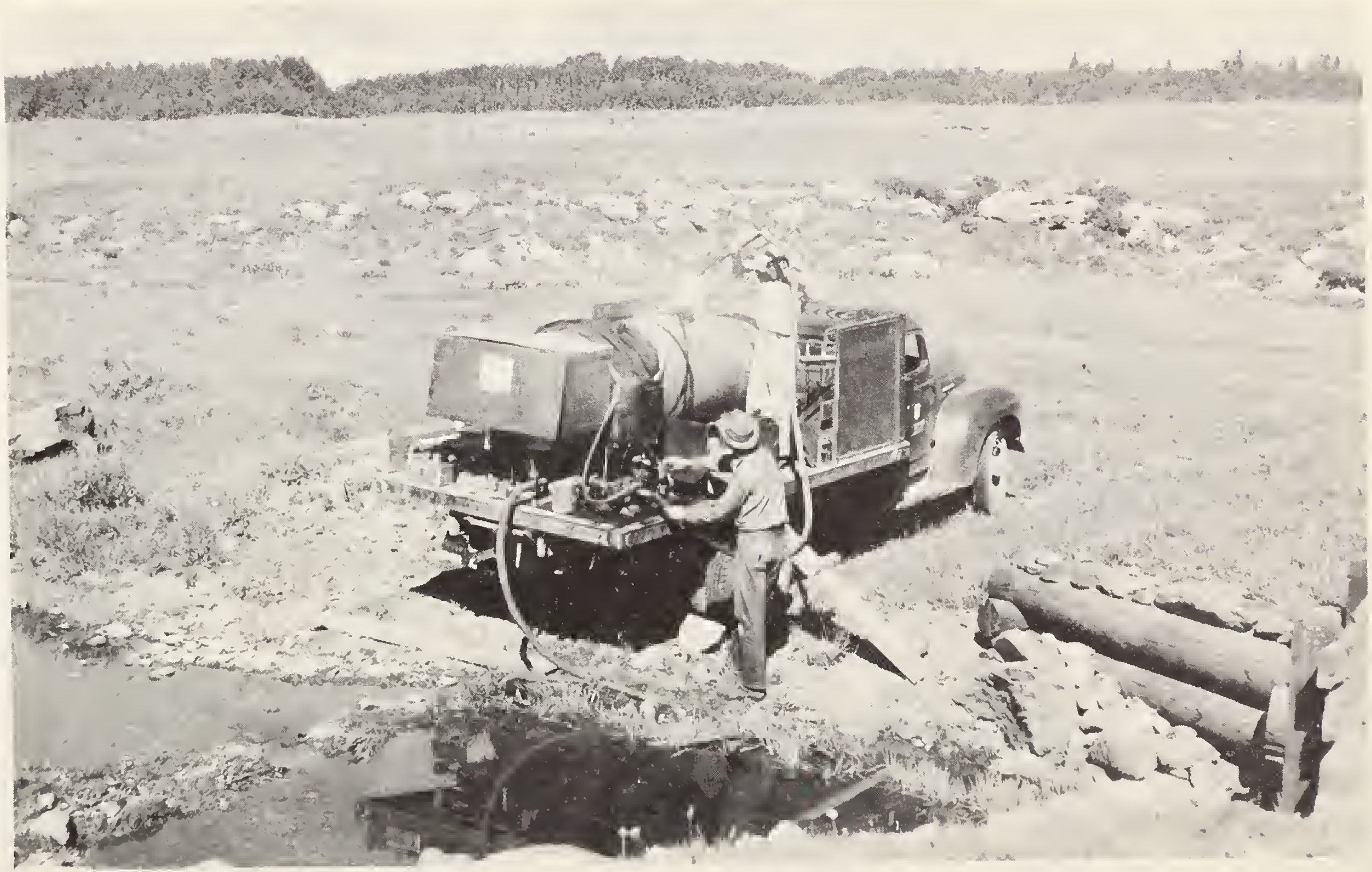

Figure 11.—Pumping water from pond formed by a hastily constructed earth dam in a small mountain stream. Tank was completely filled in 8 minutes. Sampling site in middle background this side of timber was one-half mile from water supply. Elevation: 9,600 feet. Black Mesa, Colorado

The standard truck side and end gates are used to transport equipment on long hauls, whereas the specially constructed low sideboards are used during short hauls and field tests for speed-up in operation.

FIELD PROCEDURE

All runs are made on pre-wetted soils. Pre-wetting the soil prior to the test run serves a threefold purpose:

1. bringing surface inches of soil to field capacity and uniform moisture content;
2. facilitating insertion of plot frames in soil;
3. minimizing soil disturbance during installation of plot.

Soil moisture is one of the most important factors influencing infiltration rates (7,14). Rowe (14) found that the infiltration rate of a fine sandy loam in the Sierra Nevada foothills in California was more than 10 times greater when air-dry than when at field capacity. He suggests the influence of soil moisture may best be measured by a series of test runs on certain plots by varying moisture contents from air dryness to field saturation.

Since infiltration rates vary considerably with soil moisture, it is preferable to reduce this factor to constancy in most studies. This is accomplished by bringing the surface soil to field capacity. Otherwise, variable soil-moisture conditions existent within and between sampling sites during a single field season and between seasons and years would prevent standard comparisons. Rates, obtained on pre-wetted soils, more often approach expected minimum infiltration rates and maximum erosion rates experienced during rainstorms.

PUMPING WATER

In our Colorado studies we have always hauled water to each site tested. The closest source of water was located at the time of site selection and a few sites discarded because of excessive distance to water. Our hauling distance usually over rough roads and cross country averaged about 3 but never exceeded 10 miles.

Often we found it necessary to improve the water source for pumping purposes by either digging out a spring, building a small earth dam across a stream, or temporarily diverting water into a small pond. Providing a suitable water supply in semiarid and arid regions may be time consuming and reduce productive output, but it seldom prevents sampling.

The pumping operation is briefly described and shown in figure 11. One end of the suction hose is attached to the hose nipple inserted in the gate valve and the other end with strainer placed in the pond. The strainer should be laid on a flat rock placed on the bottom of the pool to elevate the opening above sand or silt. The strainer should also be entirely submerged for best results. One end of a short section (15 or 25 feet) of linen hose is attached to the 1½-inch outflow nipple of the relief valve and the other end placed in the water tank. The by-pass and "coolant" water hoses are also placed in the tank. Both 1½-inch gate valves are opened and water remaining in the tank allowed to drain and fill the line. This procedure is the most efficient although water can be pumped without filling the line. The pump is started and after a few minutes of pumping from the tank the gate valve nearest the tank is closed and pumping continued until tank is filled. This usually requires 8 to 20 minutes.

INITIAL WETTING

The soil is pre-wetted by sprinkling for 20 minutes with rainfall applicators at about 5 inches per hour intensity. It is desirable to bring the surface soil to field capacity without causing any erosion from rainfall impact and splash during initial wetting. A screen grid is therefore used. This 16-mesh wire grid is placed directly over the soil, or herbaceous or shrubby vegetation, whichever is the tallest (fig. 12). Pins made of No. 8 gage wire are used to hold grid at proper height. The closer the grid is placed to the soil, the less opportunity for splash erosion and soil dispersion. The minimum amount of surface runoff should occur during this initial wetting. When three nozzles are used and surface runoff is high and turbid, one nozzle should be turned off for the balance of the run, providing surface runoff continues.

In the design of new equipment it may be well to consider adding fog nozzles of the North Fork (13) type in addition to F nozzles on each applicator. Interchanging nozzles for initial wetting and test runs is not recommended.

All soils should be allowed to drain for a period of at least 24 hours. On coarse-textured soils with permeable subsoil, 6 to 12 hours may be adequate, but 24 hours provides a safe margin (3). Medium-textured soils (loams) generally require 24 to 48 hours, and fine-textured clay soils and those with developed B horizons may require 96 hours or more. The drainage period chosen should not only meet necessary requirements of soil moisture, but should also best fit the needs of the operation schedule. Since all plots are covered with tarpaulins between initial wetting and test run, a longer drainage period is preferable to one too short.

INSTALLING INFILTROMETER

The technique for installing the infiltrometer follows:

Plot Frame and Rain Trough

Plot frame is installed only after a satisfactory drainage period has elapsed since initial wetting. Canvas plot cover is removed, exposing location pin in center of wetted area. The pin also elevates the tarpaulin during the drainage period, thereby preventing flattening or

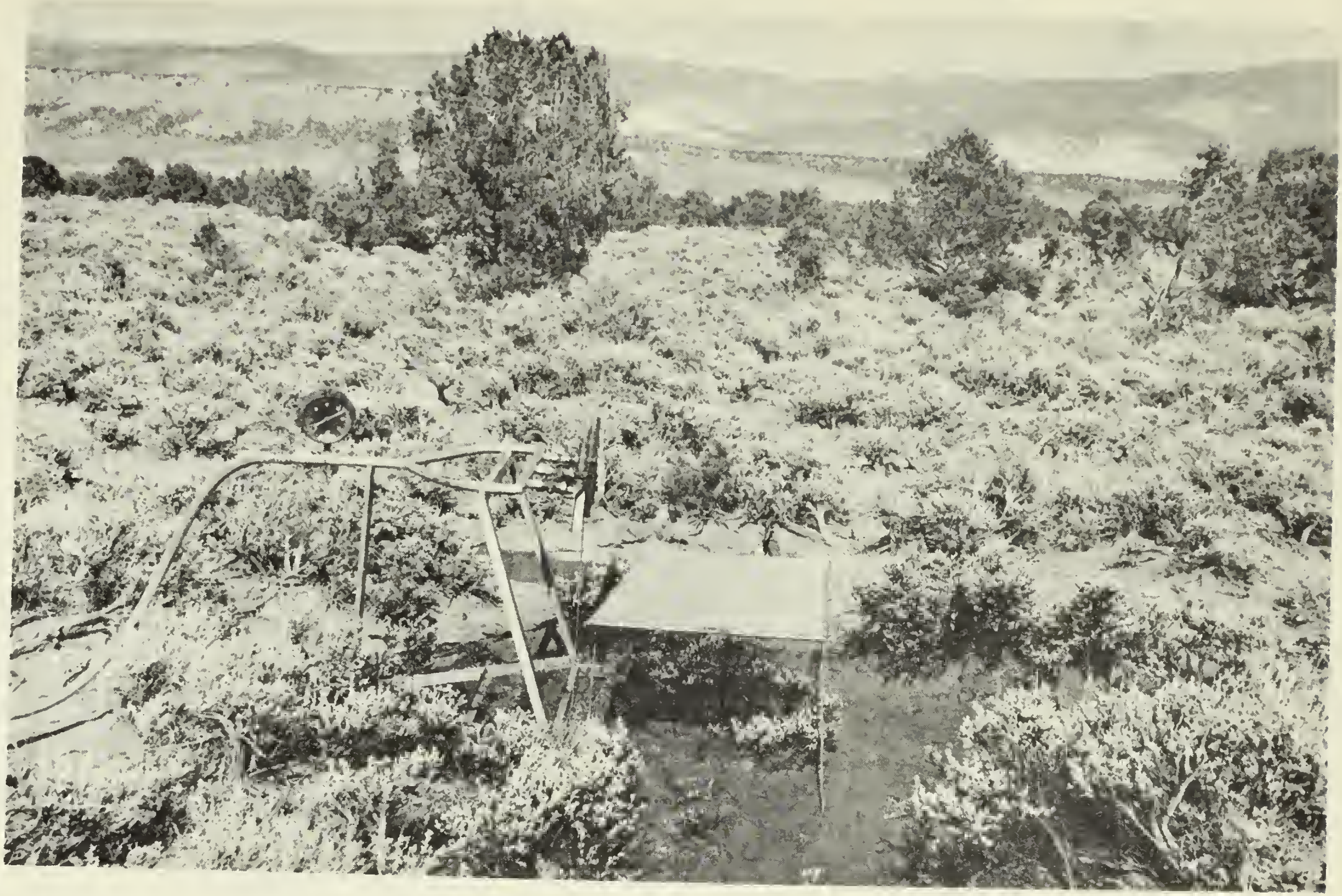

Figure 12.—Initial wetting infiltrometer plot position in sagebrush park of Western Colorado. Windbreaker tent is used except during calm periods.

matting of herbaceous vegetation. The lower left hand corner of plot frame is set against the pin so that sides of frame are parallel to the direction of steepest slope. The spirit level is placed in the middle of the frame, shown by markings, and at right angles to the direction of slope. Frame is rotated slightly until it is practically level.

The next step is to remove all surface stones or rocks, small twigs and branches, and other undesirable material that lies directly under the plot frame walls. This is usually necessary to prevent disturbance of soil enclosed within plot frame. It is also advisable to carefully remove any tree or brush branches larger than 2 inches in diameter and 12 inches in length.

The two tamping blocks are next placed over the top of the plot frame. The operator stands on the downhill block in squatting position and lightly taps the uphill block several times with the 4-pound sledge hammer. He then shifts his position to uphill block and gently taps the downhill block. Plot frame need only be inserted about 1/4 inch during this initial step.

Blocks are then removed and the sharpened mason's trowel is used to cut a 2- to 3-inch groove along the outside wall of the frame, but should never be used on the inside. At the lower end it is necessary to carve out a soil wedge to allow runoff collector trough to enter soil easily. This wedge should start from the soil surface at cut-off wall and approximate a 2-inch depth about an inch downslope from the plot frame.

The tamping blocks are replaced on plot frames and the previously described method of tamping employed until plots are inserted to proper 3-inch depth.

Due to the usual unevenness of ground surface, the depth to which plot walls are inserted into the soil will vary. A minimum depth of at least ½ inch is necessary at all points along the frame wall. It is necessary to check the frame occasionally with spirit level, during the tamping process, so that it remains level when inserted to proper depth. When properly set[12] most of the angle iron along sides and back of frame should be flush with the mineral soil. The upper end of the runoff collector trough should be slightly below the lowest level of mineral soil in contact with the trough. Care should be taken in setting frames on areas with heavy litter or other dead organic materials. They should always be set to the soil surface. In areas with deep litter accumulation, the top of plot frames may set less than 1 inch above the litter. Satisfactory results may be obtained even under these conditions, since there is little danger of rainfall splash loss where heavy litter is present.

12/ Whenever operator is unable to tamp plot to correct depth due to rock interference, the frame is moved to a new location. Our procedure is to move plot frame 1 to 2 feet to the left, then to the right, and finally above the original location. If interference is repeatedly encountered, an entirely new location is selected by drawing new random numbers.

The next step is that of recording slope percent by averaging two readings, one on each side wall. Amount of soil, rock, live and dead organic material is next recorded by placing grid over the plot frame. The aerial or ground material intercepted at each cross wire of grid is recorded on reverse of provided form, RI-7 (fig. 17, Appendix). No. 8 gage wire pins should be used where herbaceous or shrubby vegetation extends above the top of the plot frame.

The rain trough is next placed on the plot frame and centered. The lower rainfall cutting edge should be directly above the upper edge of runoff collector trough. The spirit level is used for checking this relation.

The trash collector screen is then placed over the runoff collector trough. The plot frame and rain trough are next covered with a tarpaulin. Finally, a hole is dug at the extremities of runoff pipes for placement of two 1-gallon containers.

Windbreaker Tent

The windbreaker tent is next installed. This is a one-man job when properly executed, though operators may prefer to install these as a team. The method used by a single operator follows:

> Drive in four stakes at approximately 15 feet from each plot corner. Hook proper guy rope around one front stake. Place rolled-up windbreaker tent in upright position. Unroll tent and engage guy ropes at respective stakes. Fasten tent door with hooks. Tighten guy ropes and adjust tent position.

The tent opening is always placed downhill so as to facilitate checking the rain pattern, plot runoff, and erosion during the test runs (fig. 9). When the wind is light and from a different direction than tent opening, it is not necessary to keep tent completely closed.

The tent is easily dropped and rolled up by a single operator. Usually this is accomplished while lag runoff is draining into the 1-gallon cans after completion of the run (fig. 13).

Rainfall Applicator

It is desirable to install the rainfall applicator last. This will prevent its being thrown out of adjustment and plumb, before commencing the field run. To facilitate installation, it is usually necessary to first remove litter, vegetation, and a few inches of soil from the area to be intercepted by the outer half of the applicator base. The applicator is then placed alongside the frame. The 4-inch guides extending beyond the applicator base are set on the angle iron of plot frame. The base is next moved up or downslope until beaded chain suspended from

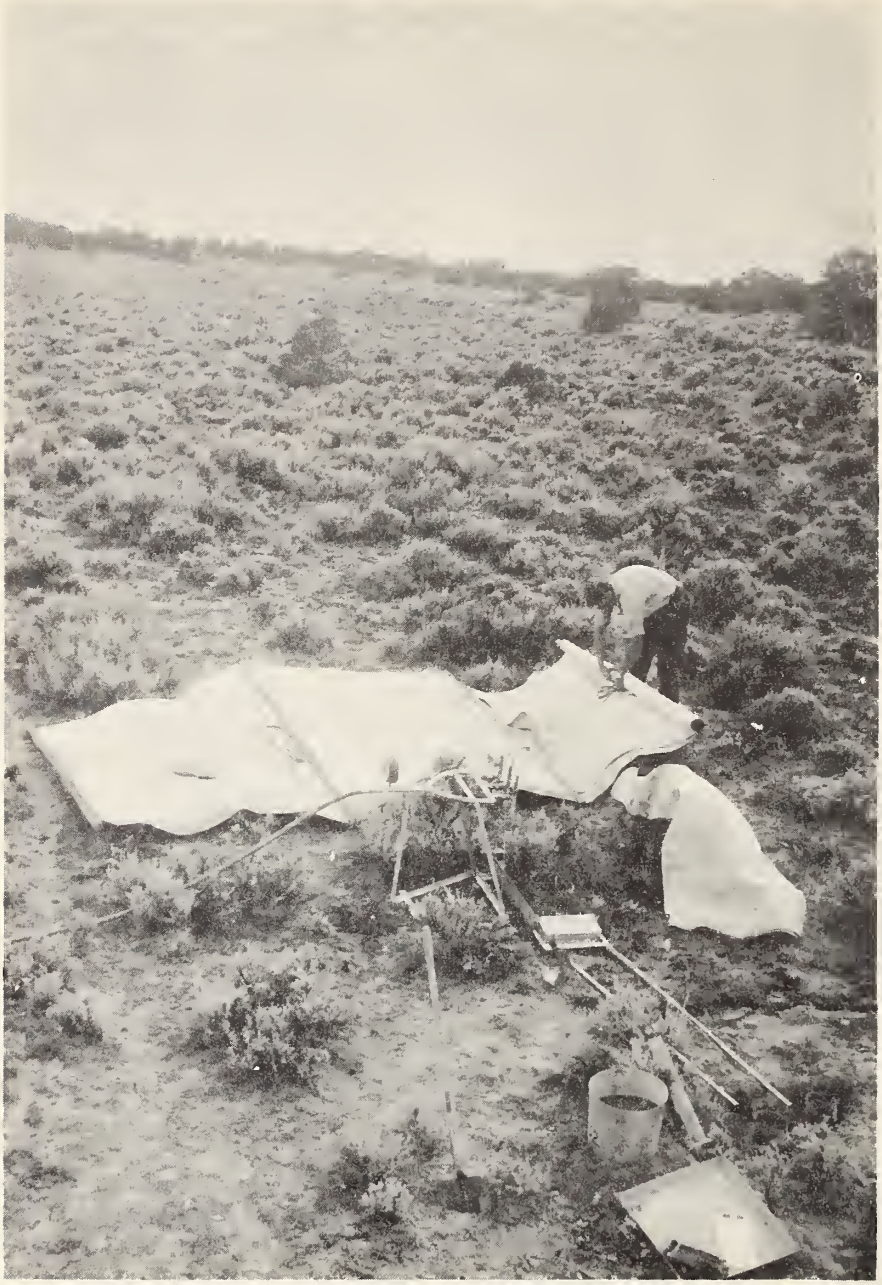

Figure 13.--Infiltrometer field set-up in sagebrush park, Western Colorado. Operator is rolling up windbreaker tent after completion of run. Note turbid runoff water in sediment can, canvas plot cover, and 1-gallon collector cans set in dug trench.

middle nozzle, when plumbed, coincides with painted mark at middle of trough side (fig. 14). With the spirit level inserted in guides at base of applicator it is pushed into the soil until level. Nozzles are plumbed with the pipe level (fig. 5) by rotating street-elbow. Next, any vegetation extending beyond plot walls is cut so that rain does not meet any interference in its downward descent toward troughs (fig. 14).

OPERATION DURING INFILTRATION-EROSION TESTS

When plot frames, rain troughs, applicators, and windbreaker tents are installed, operators are ready to start field test. The field test is conducted for a 50-minute period at a constant rainfall intensity of about 5 inches per hour (fig. 15). The reasons underlying selection of about 5 inches per hour artificial rainfall rate in our studies is explained in detail so that an investigator may decide on the most appropriate rate for his own region.

If a valid and accurate measure of the infiltration and erosion rate of a given surface soil condition is desired, then artificial rainfall must be applied at a rate in excess of the expected infiltration rate. Only when rainfall excess is maintained will a measure of infiltration and erosion be obtained. Whenever surface runoff is not produced, the rate of water intake equals the rate of rainfall application and no opportunity exists for soil loss or erosion.

The minimum amount of rainfall excess necessary to adequately measure the infiltration rate with this equipment appears to lie between 1 and 1.5 inches per hour (3). This amount of runoff insures rainfall excess from most of the plot area. Apparently, this rate of surface runoff is also satisfactory for an accurate measure of the soil-erosion rate.

It is therefore essential when desiring relative rates of infiltration and erosion for all differential vegetated, littered, and bared surface soil conditions to apply artificial rainfall at a rate well in excess of the maximum expected infiltration rate. In most studies, however, the investigator is not interested in learning the exact infiltration rate of all conditions, particularly those having a rate of water intake in excess of the maximum rainfall intensity experienced or to be expected. It may suffice to know that a particular vegetation-soil complex will not produce either surface runoff or erosion under the most severe storm conditions to be experienced in the general locality.

In our Western Colorado investigations, we are using a rainfall application of from 5 to 5.5 inches per hour. The maximum 5-minute rainfall intensity on record is approximately 5 inches per hour; therefore the infiltration rates of vegetation-soil complexes in need of testing should not exceed 5 inches per hour.

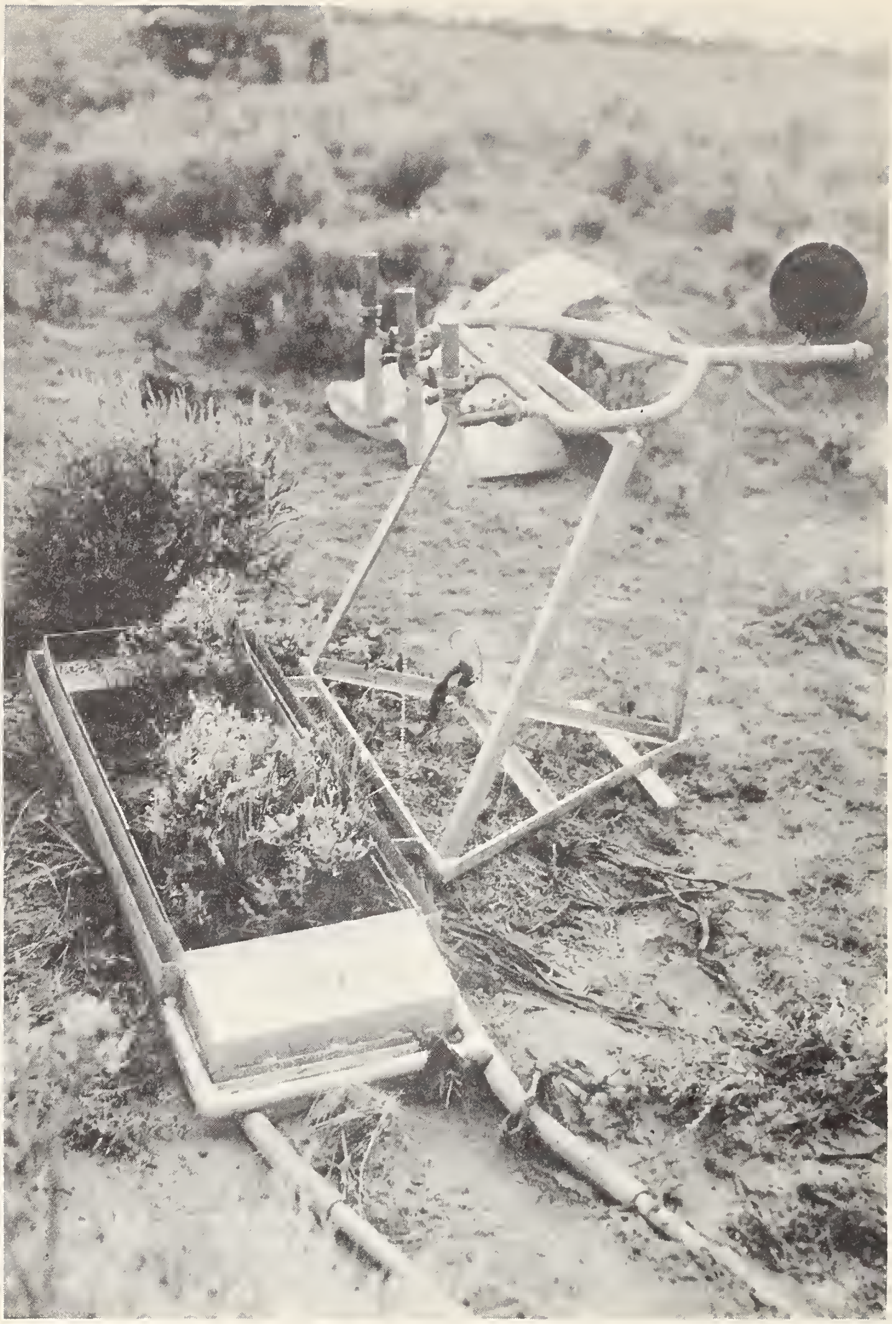

Figure 14.--Close-up view of rainfall applicator, plot frame, and rain troughs in field installation. Note sagebrush plant within plot boundaries. Sage plants up to 2 feet in height can easily be sampled.

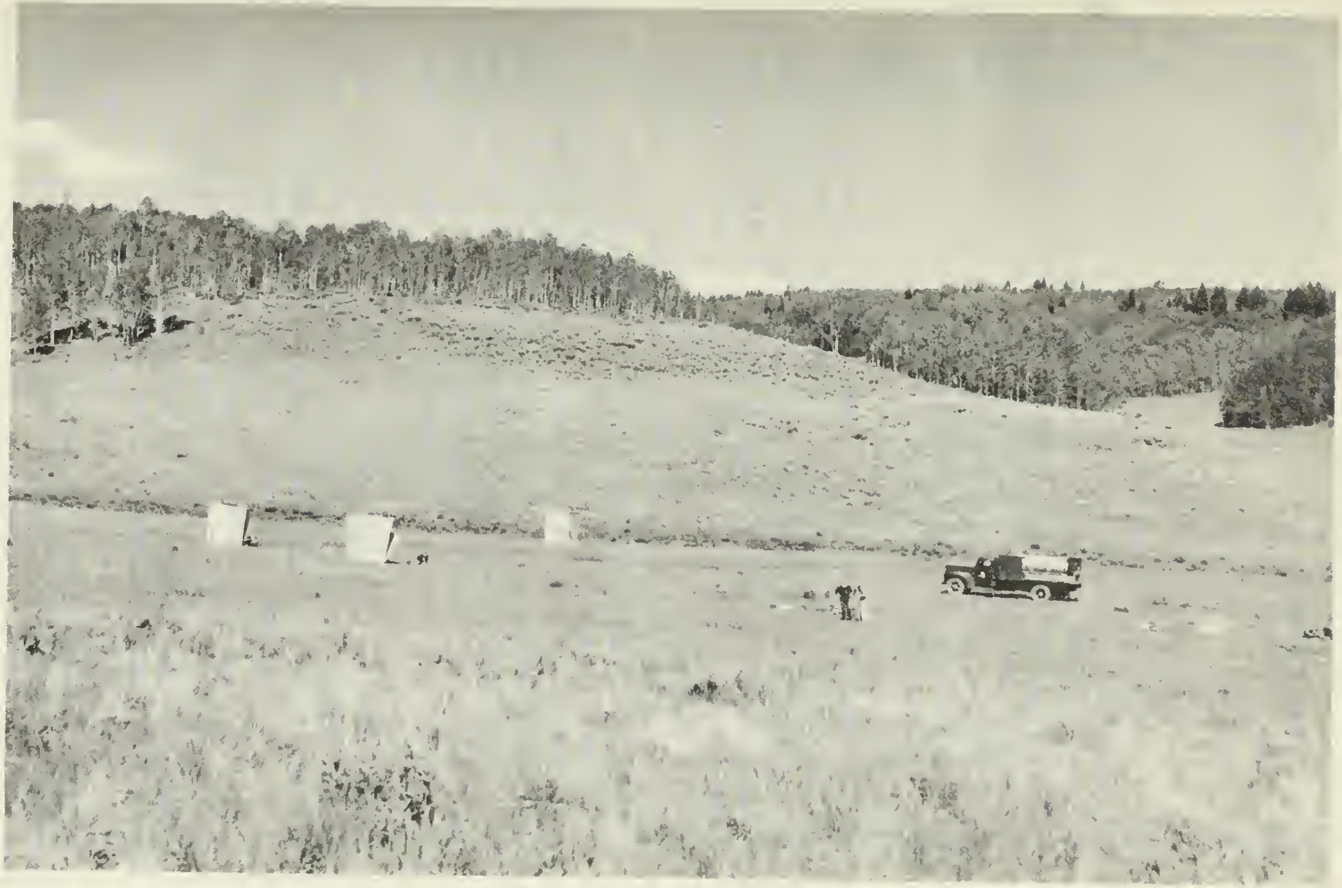

Figure 15.--General overall view during an infiltration-erosion run. Tests are being conducted in the 2 tents on the left. A second run was conducted without moving the truck. Other tent is off the photo to the right. Vegetation is bluegrass and slope is 10%, but all areas shown can easily be sampled. Black Mesa, Colorado. Elevation: 9,500 feet

Most infiltration curves approach a low, near-constant point within 20 minutes, and practically all curves reach this minimum rate after 30 minutes of operation. Therefore, the 50-minute run provides a 20-minute period of minimum constant infiltration rate for statistical analysis.[13] Erosion losses are based on the entire 50-minute run and may be expressed both in tons per acre per hour and tons per acre per inch of surface runoff.

The pump engine is started and water is pumped through the circulating system to force out all entrapped air. Water is next cut off at siamese valve and allowed to by-pass into storage tank. Both 3/4-inch hoses are coupled to applicators and water turned on again at siamese valve. Once the rainfall becomes steady as judged by the pressure gages, the run is started. Operator quickly removes canvas cover and starts stopwatch simultaneously. Each operator is equipped with a stopwatch to facilitate timing. The time of start of runoff from plots and troughs is recorded on form RI-7 (see figure 17 - Appendix).

Runoff from plot and rain troughs are collected separately in 1-gallon cans. At 5-minute intervals, the two runoff pipes are raised to temporarily stop runoff and the two 1-gallon cans containing runoff water are replaced with empty ones. The 1/2-inch pipes are lowered and runoff water allowed to collect again in 1-gallon cans. Water collected in each container is measured volumetrically in 1,000 ml. lucite graduates. Rainfall water is discarded, but all runoff water and sediment is deposited in a sediment can (fig. 13).

Each operator should dig a small ditch to divert runoff water, from area surrounding plot, away from operator's location and equipment. He will also be kept reasonably busy checking and adjusting nozzle water pressure by means of the needle valve at siamese coupling. A pair of field glasses will aid in viewing pressure gage needle, at great distances, and should be left at the siamese position. Operator should check uniformity of rainfall and plot runoff rates. He will often find it necessary to clean trash screens and runoff pipes. Trash screens when clogged should be temporarily removed, rinsed in sediment water, and quickly replaced. Pipes are cleaned by raising and blowing out any accumulated debris. Operator should also ocularly inspect uniformity and height of rainfall pattern, and delivery at nozzles from time to time. He should check runoff and erosion occurring over plot and make necessary notes such as depression storage, water turbidity, seepage, pressure variation, and other pertinent remarks.

After 50 minutes have elapsed since start of the run, infiltration-erosion test is terminated by throwing the canvas cover over the plot frame and rain troughs. The partially filled 1-gallon runoff cans are replaced with empties at the same time. This operation requires two operators for precise measurement. If operators stagger their start of runs by 2 or 3 minutes, they can assist one another during this operation. Each operator records the time at end of runoff from his plot and troughs. When runoff drops are spaced more than 10 seconds apart, runoff is considered ended, and the amount of lag runoff from both rain troughs and plots is measured volumetrically and recorded. As soon as first operator completes his test he turns off the water to his nozzles at the needle valve. The last operator to complete his run immediately shuts off the pump to conserve water.

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[13] Recording of data is such that individual infiltration curves, initial wetting, depression and detention storage, and other pertinent factors may be determined when desired.

After lag runoff has ceased, the trash collector screen is removed and rinsed off in the runoff water collected in the sediment can. Most of the sediment remaining on the runoff collector trough, if appreciable, is transferred by means of a small trowel into the sediment can. When this amount of sediment is large it may be preferable to transfer directly into an 8- or 16-ounce soil can. The residue sediment is washed into a 1-gallon can with collected runoff water. This turbid solution is next deposited in the sediment can which is placed near a tree, fence, or other protective barrier, when available, or in the hole dug for the 1-gallon cans. Soil is also piled around the base to hold it stationary and prevent its overturning by animals. An empty tray is placed over the sediment can and a medium-sized rock placed on the tray. The partially filled soil can is placed alongside the sediment can.

With an experienced crew the work can often be expedited by having one operator record data from both plots during the test run. Meanwhile, the second operator inserts the other set of plot frames into the soil, erects windbreaker tents and performs other chores in preparation for the next run. This procedure is not practical when the 2 plots are spaced more than 200 feet apart or separated by a fence. On occasion, one operator has conducted an entire run without assistance, but this is not recommended for continued operation.

The pump and engine (Pacific Marine, Type "Y") seldom require much attention or care during runs. On occasions, the engine will falter and stop. The following procedure is used whenever the pump engine fails during the 50-minute run:

> Runoff tubes should immediately be diverted from 1-gallon containers and plot covered with tarpaulin. Stopwatch needle should be stopped at the same time. Runoff water is left in 1-gallon cans. Once the pump engine is again operating satisfactorily and pressure as read by gages is uniform, the run may be resumed. Canvas cover is removed and runoff allowed to return to its former rate by measuring volumetrically at 1-minute intervals. When runoff rate is back to that occurring at the time of pump failure, the run is resumed and runoff water collected for the necessary time needed to complete the 5-minute interval, previously interrupted.

At completion of the field run the 3/4-inch hoses are uncoupled and coiled. The two 50-foot sections of hose attached to the siamese assembly are not disconnected at that end. The operation is speeded up by carrying and transporting the siamese assembly and coiled hoses as a unit (see figure 3). Plugs are inserted into the open female couplings to exclude soil or other extraneous material. The other sections of 50-foot hose are coiled separately and the male and female couplings fastened together. Rainfall applicators, plot frames and runoff troughs are removed, location pin replaced and plot area covered with a tarpaulin. The canvas cover should be placed so that vegetation within the plot area is not matted. Medium-sized rocks or soil should be placed at each corner of tarpaulin to prevent its displacement by wind or other cause.

The most efficient field procedure employs a 2-man crew for operation of equipment. If a 3-man crew is available, two sets of plots and tent enclosures are necessary. Even with the 2-man crew, the extra set of apparatus speeds up operations considerably. When insufficient time remains for a 50-minute run before "quitting time," the extra plots and tents may be installed and made ready for the next day's operation. Additional apparatus is also needed for installations conducted during the pre-wetting process. When tents are used in the initial wetting, it is advantageous to leave them in place until completion of the run. The two members usually work as a team during initial wetting operation, assembling and disassembling, loading, unloading and installation of apparatus.

Plots may be separated by a distance of 15 to 300 feet. It is necessary to use good judgment in parking truck and placing siamese coupling. These are usually parked midway between plots, but often this is undesirable, where trees, brush, or other barriers obscure vision. The 300 feet of 3/4-inch rubber hose is about the maximum amount that can be handled satisfactorily. Longer hose lengths become unwieldy and slow down operations considerably.[14]

When water is available at the site to be sampled, it may be pumped directly from the source. This may occur quite often in humid and sub-humid regions or irrigated areas. In such instances, considerably more 1½-inch canvas hose may be needed. In most sampling (all of that encountered by the writer) water will need to be hauled to the site. Sampling areas at great distances from any source of suitable water supply should be avoided, if possible.

During regular field operation the water storage tank is filled twice a day. This is usually done in the evening or early morning at camp or town and during the lunch hour.

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[14] New type light-weight plastic hose should be considered in assembling new equipment. It is believed that 5/8-inch hose will work as well as the 3/4-inch size if made of durable material.

With a well-trained crew of two men under normal operating conditions, a maximum of six plots, or three complete runs, can be completed on most days. This includes the pre-wetting operation. The field-season average will be much lower because of break-down and maintenance of equipment, particularly the pump; making and breaking field camp; moving between camp sites; extremely long hauls to water, illness; and other factors.

During the 1948 and 1949 field season, we averaged about four plots per working day. Sites were scattered over the Western Slope of Colorado. Each season was commenced with a new crew of totally inexperienced operators. It took the entire field season before operators were working at full efficiency. The daily average should vary between four and six plots per day depending on personnel experience, concentration of work areas, and proximity to water.

EROSION MEASUREMENTS

After 6 days have elapsed since completion of the infiltration-erosion test, the plots should be re-visited and water siphoned from the sediment cans. This amount of settling time was found necessary from a study conducted in Western Colorado during 1948 and 1949. Table 4 shows the portion of total soil loss left in suspension for differential soil types, settling periods, and amounts of erosion. This tabulation includes results from 250 plots taken at elevations ranging from 5,800 to over 10,000 feet. Soils varied from loamy sand to clay and included sandstone, shale, and basalt parent material. Soils of sandstone and shale origin were sampled in the pinyon-juniper and sagebrush vegetation types, and shale and basalt in the grassland type. Ground-cover density of live and dead organic materials varied from 0 to 100 percent. The number of days allowed for settling ranged from 1 to 30 days. A flocculating agent was tried at the start of the study, but discarded as it did not materially speed up or increase the amount of settling.

Table 4.--Portion of total soil loss left in suspension for differential soil types, settling times, and erosion amounts

Season	Soil origin	Average texture	Total soil loss per plot			
			More than 100 gm.		Less than 100 gm.	
			Settling days		Settling days	
			6 or more	Less than 6	6 or more	Less than 6
			%	%	%	%
1948	Dakota Sandstone	Sandy loam	--	0.8	--	3.4
	Mesa Verde Sandstone	Fine sandy loam	0.7	2.9	2.4	8.8
	Morrison shale	Clay loam	0.6	--	--	0.3
	Basalt	Loam	0.9	1.2	1.6	6.1
1949	Dakota Sandstone	Sandy loam	1.1	2.0	1.5	2.5
	Mancos shale	silty clay loam	--	0.7	--	1.1
	Wasatch shale	Clay loam	0.2	0.2	[1]9.7	--

[1] 8 plots averaged only 30 gm. of soil loss

Relatively clear runoff water is siphoned from sediment cans with 1/8-inch rubber hose to about 1 inch or less of the bottom, depending on degree of settling. The sediment and water is next swirled in the can and washed into the tray. Remaining water or moisture in tray and can is allowed to evaporate by exposing containers in direct sunlight and to the wind action.

The dry sediment is brushed from the can into the tray and subsequently into the 8- or 16-ounce sampling cans. In our studies we found it took from 1 to 4 days after siphoning excess water before sediment was dry enough to transfer into 16-ounce cans. In humid regions, the modified technique described below and used during rainy periods should suffice.

> Trays are placed upside down over a frame made of No. 8 galvanized wire and placed at top of sediment can. The elevated tray allows free air circulation around the inside of sediment can, but also deflects all rain water. We usually place cans on top of brush or shrubby vegetation when available, to increase rate of drying. All drying may be conducted indoors if the sediment is washed into quart jars after siphoning.

Sediment in soil cans is oven-dried at 105°C. and weighed in grams to an accuracy of one-half percent.

VEGETATION MEASUREMENTS

In addition to the vegetation density count taken just prior to the test run, it is also advisable to estimate ocularly and individually the density of shrubs, grasses and weeds by species or broader grouping and the density of dead organic materials and soil. These estimates should provide a check on the grid count as well as additional information. This procedure will also furnish data on the amount of organic materials washed from the soil during the field test and the amount of soil, dead organic materials and low-lying live plants over-topped by taller vegetation. Plant composition, vigor and air-dry weight of live and dead organic materials should be determined. These factors influence infiltration and erosion rates and are essential for description and classification of most sites. Average height or length of ungrazed leaves of certain herbaceous plants serve as a fair criterion of plant vigor. Average depth of litter and humus is also needed.

Composition, density and vigor of shrubby vegetation is taken first (fig. 16), then clipped and placed in paper bags for subsequent drying and weighing. Herbaceous composition, density and vigor is taken next, plants clipped at the ground line and stored in paper bags. In most studies merely separating grasses from weeds will suffice but on occasion it may be desirable to separate species. After removal of all live vegetation the type, density and depth of dead organic materials is recorded. Exposed soil (bare ground) and rock density is taken next. Dead organic materials are then collected and stored in paper bags. When practical, humus and litter are collected separately.

Organic materials should be weighed in grams to 1/2 percent accuracy when adequately air-dried.

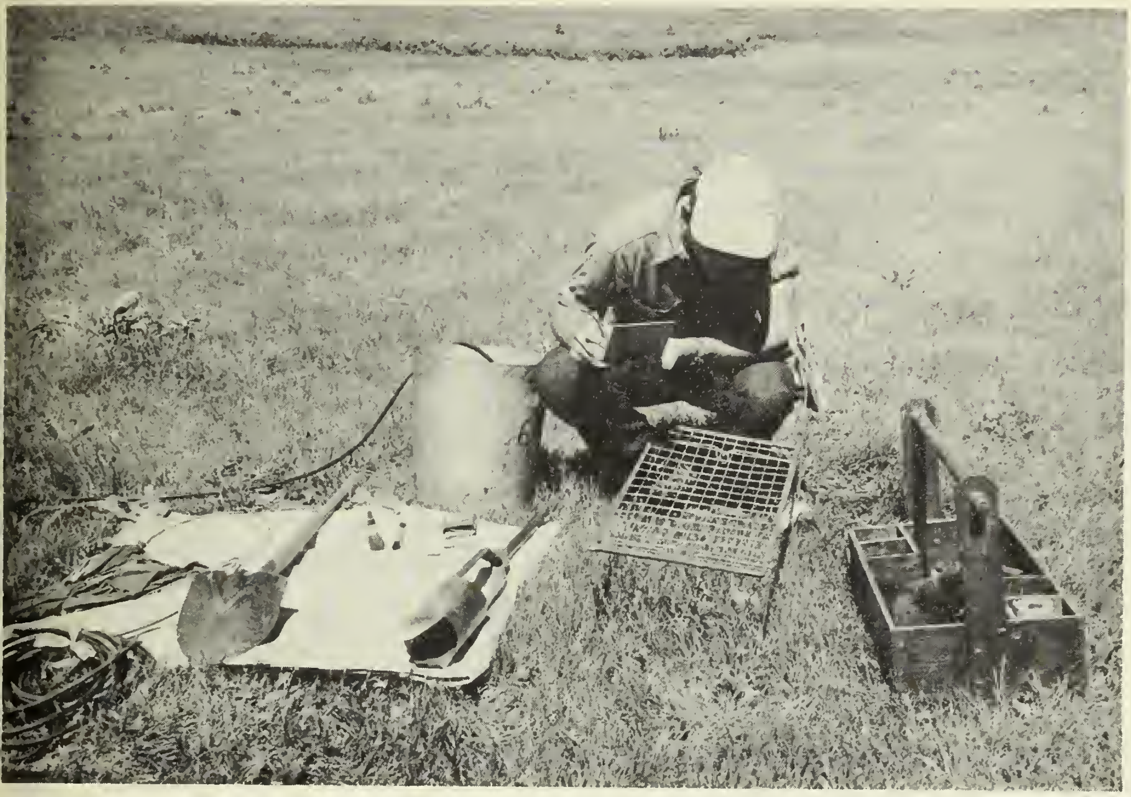


Figure 16.--Recording density of live and dead organic materials, soils and rock with aid of plot grid several days after the field test. (The grid is normally used for recording distribution and density of organic materials before the infiltration test.) Meanwhile water is siphoned from sediment can. Carrying box on right holds soil, sediment and vegetation sampling equipment. Special type soil auger (12) at left of plot grid.

SOIL MEASUREMENTS

Excepting for special studies of infiltration, erosion, and vegetation relationships, it is doubtful that more than the following soil factors need be measured:

1. Complete soil profile description, including parent material, geomorphology, soil reaction (pH) and presence or absence of lime;
2. Depth to solid rock;
3. Depth of moisture penetration;
4. Lateral movement of moisture within the soil profile;
5. Size, depth, and number of animal burrows and other disturbances;
6. Degree and depth of rooting.

These factors should aid in characterizing the site, understanding infiltration-erosion relations, and explaining any erratic runs encountered.

The field method employed consists of digging up the entire plot with a shovel to a depth of about 1 to 2 feet after removal of vegetation and litter. A soil auger (12) is used to penetrate soil to rock.

In certain studies it may be desirable to study the relation between infiltration-erosion indices and soil porosities. A method is described (2) and some results of a study in pine-bunchgrass are given (3).

COMPUTATION OF FIELD DATA

INFILTRATION

Factors for conversion of volume of runoff in cubic centimeters to runoff rates in inches per hour are necessary for each piece of equipment, since they seldom are made to exact specifications and, moreover, they change dimensions during use. The formulae are presented for determination of average rate of runoff from troughs and plots during the last 20 minutes of a field run. In computations for 5-minute or longer intervals, the formulae must be altered accordingly.

> Formula used in converting cubic centimeters of runoff from rain troughs to rainfall intensity rates in inches per hour for a 20-minute interval:

$$\text{Trough intensity rate (inches per hour)} = \frac{[\text{20-minute runoff(cc.)}][\frac{60}{20}\,(0.061023)]\,[\text{correction factor}]}{[\text{Trough area (sq.in.)}]\,[\text{cosine of degree of slope}]}$$

Formula used in converting cubic centimeters of runoff from plot enclosure to surface runoff intensity rates in inches per hour for a 20-minute interval:

Plot frame intensity rate (inches per hour) =

$$\frac{[\text{20-minute runoff(cc.)}]\ [\frac{60}{20}\ (0.061023)]}{[\text{Plot frame area (sq.in.)}]\ [\text{cosine of degree of slope}]}$$

From the above formulae, constant conversion factors may be obtained for each plot and rain trough equipment. It is then only necessary to multiply the total cubic centimeters of runoff by the conversion factor and divide by the cosine of the slope percent.

EROSION

The formulae used in computing soil loss from each plot:

Total soil loss per plot (gm.) =

$$[\text{Soil loss left in suspension (gm.)}] + [\text{Soil loss that settled(gm.)}]$$

Soilloss left in suspension can most often be disregarded (table 4).

Total soil loss per plot (tons per acre) =

$$\frac{[\text{Total soil loss per plot (gm.)}]\ [43{,}560]}{[453.6]\ [2{,}000]\ [\text{plot area (sq.ft.)}]\ [\text{cosine of slope percent}]}$$

The above formula may be reduced to a constant that is divided by the cosine of the slope percent and multiplied by the total soil loss.

EXPERIMENTAL DESIGN

The experimental design and sampling procedure will vary with each study, depending on objectives to be attained. Infiltration-erosion studies with the Rocky Mountain infiltrometer lend themselves readily to statistical analysis. Analysis of variance, covariance and students "t" tests may all be employed (15). In addition to testing reliability of mean values of main effects, it is also possible to determine relationships between infiltration and erosion values and concomitant factors of vegetation and soil by regression analysis.

The success of any infiltration-erosion study will largely depend on the adequacy of sampling. This necessitates an understanding of infiltration-erosion and factors influencing it. In all studies the following factors must be given careful consideration:

1. Sampling by homogeneous infiltration-erosion strata so as to reduce the number of samples to a minimum, yet obtain a reliable measure of the mean.
2. Selection of plots within each strata at random so that error terms are valid.
3. Determination of experimental and sampling errors.

The Rocky Mountain infiltrometer is particularly adapted to testing comparative infiltration-erosion rates along fence lines where differential grazing or other land uses have altered soil and vegetation conditions. It is also adapted to any comparative measurement employing paired plots such as between two types of vegetation, soil, geology, or land use.

This is due primarily to the design of the infiltrometer, which permits testing two plots during each run. The sole limitation is that it is not practical to space two plots more than about 300 feet since the amount and weight of hose becomes unwieldy. Even at this maximum spacing the operators must check water pressures on gages by means of field glasses and oftentimes must prune tree branches and clear brush in line of view of pressure gages.

Most efficient random sampling is accomplished by sampling paired plots (two conditions) during a single run or by restricting randomization of the two plots of a single run to a square area of 1 acre. This provides 209 feet on a side and 295 feet on the diagonal allowing complete randomization within the acre.

For large areas, stratified random sampling will usually prove the most efficient design. It is usually possible to divide large areas or watersheds by topographic units of similar elevation, slope, aspect, and geomorphology. Moreover, when land use, cover, and soil type are considered, homogeneous infiltration-erosion strata are usually small. It is preferable for reliability of mean values to sample a greater number of widely distributed small homogeneous sites than a few large areas. But the larger areas have the advantage of more compact sampling and a greater number of tests per unit time as travel time and camp set-ups are reduced.

But when sampling on a watershed or other basis, the sampling unit will usually exceed 1 acre in extent. A proposed method is outlined:

> Map in the boundary of the homogeneous complex. Subdivide this area into 1-acre square plots. Number plots consecutively and draw numbers at random from a table of random numbers (9,15). The range of numbers drawn should equal

the number of plots, whereas the amount of numbers drawn should equal the proposed number of test runs (two plots per test).

The actual infiltrometer positions are also determined at random. A similar method to that used in determining the general location of a run is used. Subdivide each plot into the number of possible infiltrometer positions and number them consecutively. Draw two numbers from a table of random numbers and plot positions on map. The infiltrometer position is located in the field by pacing or using a steel tape. The position is temporarily marked by placing a No. 8 galvanized iron wire pin into the soil. Pieces of yellow and orange or red cloth are fastened to each pin to facilitate relocation by infiltrometists. The placement of the infiltrometer frame in relation to the pin was previously described.

Some modification of the described sampling procedures may often prove desirable. We have found that when sampling areas of 5 to 10 acres in extent with 10 or more plots a complete randomization of infiltrometer positions is usually possible. The likelihood of drawing 10 plots that cannot be paired into 5 runs of 2 plots less than 300 feet apart, is very small. Also, in the selection of infiltrometer positions, numbers may be drawn within the range of feet of a given side of the plot. Numbers are drawn for two directions or orientations and the actual location of infiltrometer determined by pacing from one corner of the plot or site.

INSTRUMENTAL ERROR AND SAMPLING VARIATION

No accurate measure of instrumental error has been determined for this apparatus. Variation in height of fall of raindrops, rate of delivery, and rainfall distribution all contribute to instrumental error. The consistency of relations obtained during the calibration runs seems to indicate that instrumental error from these causes is small. Moreover, in field studies an attempt is made to maintain the maximum height of raindrops at 7 feet and rainfall rate at 5 inches per hour by slightly varying pressures at the nozzles.

Some idea of the consistency of rainfall distribution is obtained from comparison of correction factors at the start and end of the field season. These values were within 3 percent except when applicators or nozzles were damaged in the field. Moreover, Wilm (21) concluded the variance expressing the error of the average rainfall rate was only 6 percent of the variance of the average minimum infiltration capacity, generally called the fc or constant value.

Soil, rock, and organic material disturbance during plot installation also contribute to error. This disturbance may be appreciable because of the small plot size which delimits a small area in relation to the perimeter. For this reason, great care must be exercised during plot installation if consistent, reliable results are desired.

Some idea of the error due to size of plot may be seen from comparative tests with the F infiltrometer which delimits an area of 79 square feet (6.6' x 12'). Wilm (20) found the F infiltrometer yielded slightly higher infiltration values than the Rocky Mountain infiltrometer employing a 2' x 4' plot. In a comparison of the F and FA infiltrometers during the special Bradley Canyon study of the Santa Maria Flood Control Survey (16) the infiltration rates averaged lower for the F apparatus. Likewise, infiltration rates obtained with the Rocky Mountain instrument averaged 0.3 inches/hour higher than those made with the F infiltrometer, although curves were very similar in the Flood Control Survey of the South Platte watershed (10).

It is felt that any further designed studies to test instrumental error are not justified. Variation due to soil and vegetation differences between any two adjacent infiltrometer positions can be expected to far exceed any errors due to the measuring apparatus. Field data indicate that the coefficient of variation of a single vegetation-soil complex will vary between 25 and 70 percent for areas even as small as 5 to 10 acres in size.[15]

It is generally conceded that this infiltrometer is reliable for obtaining estimates of relative infiltration (7,20). Use of this instrument for estimation of surface runoff on a watershed basis and prediction of stream flow needs further study. In the Santa Ynez Flood Control Survey (17), in California, the writer found it necessary to reduce FA derived infiltration rate curves of vegetation-soil complexes from 50 to 65 percent so as to produce surface runoff equalling that measured at the gaging station during major rainstorms. A similar comparison with the Rocky Mountain infiltrometer on six 1-acre second-growth ponderosa pine watersheds indicated that infiltration rates were too low (6). More recently, Leatham and Riesbol (8) found an apparent correlation between minimum infiltration rates determined with an F infiltrometer and minimum retention rates determined by storm hydrograph analysis.

The discrepancies are only partially due to instrumentation. Errors of measurement and variations in infiltration rates, initial soil-moisture content and storage, interception, evaporation-transpiration, rainfall intensities and volumes, and surface runoff as well as time-area relationships influenced by variances in topography, channel gradients and lengths make it extremely difficult to reproduce stream hydrographs from infiltration rates determined with this instrument. It has, however, proved suitable for determining relative rates of infiltration and erosion (3,18, 19).

15/ Unpublished data of Rocky Mountain Forest and Range Experiment Station

APPENDIX

To facilitate purchase and assembly of a complete Rocky Mountain infiltrometer, the specifications and list of materials needed are given. The 1947-48 cost of each separate item is also listed.

SPECIFICATIONS FOR PUMP AND ENGINE

Purpose: To supply a constant flow of water to rainfall applicators.

Pump and Engine Requirements

1. Pump direct-connected to a gasoline power unit or engine.
2. Pumpers should use only 80 percent of horsepower output of driving engine under normal conditions at sea level.
3. Power should be capable of continuous constant speed operation for periods as long as 4 hours' duration.
4. Pump capacity--minimum--10 gallons per minute at 100 pounds pressure; capable of producing constant pressure within 5 percent.
5. Unit -- compact and light weight.
6. General construction details:
    a. Drain valve or other simple provision for removing water in pump casing after operation;
    b. Standard screw pipe fittings on discharge and suction connections;
    c. Rope starter preferred, foot pedal acceptable, crank handle not acceptable;
    d. Gasoline tank capacity--5 gallons and mounted separate from engine.

Design and costs of recommended pumps

Pacific Marine Type "Y" Pumper

Pressure (lbs./sq. in.)	100	125	150	200	225
Gallons/minute	63	59	53	40	20

Base -- 24" x 12"
Height -- $15\frac{1}{4}$"
Net weight -- 70 pounds
Gross weight -- 145 pounds (ready for shipment)
Motor -- Gasoline, 2 cylinder, alternate instead of simultaneous firing; two impulses per revolution
Cost -- $485 f.o.b. Seattle, Washington
$150 f.o.b. Seattle, Washington (for pump replacement)

Pacific Marine Portable Type "5-A" Pumpers

Pressure (lbs./sq.in.)	80	100	140	180	220	275
Gallons/minute						
5-A-5	-	16	15	13½	12½	6
5-A-7	-	25	22	19	15	-
5-A-8	32	29	23	18	-	-

Base -- 18½"x12"
Height -- 12½"
Net weight -- 38 pounds
Motor -- Gasoline, 2 cylinder, 2-cycle, alternate firing type, magneto ignition, 5 H.P. at 4000R.P.M.
Cost -- $410 including accessories, f.o.b. Seattle,Washington

SPECIFICATIONS FOR TRUCK AND ACCESSORIES

Purpose: To provide means for transporting infiltrometer equipment and necessary water to plot locations.
Design and materials: 1½-ton capacity, stakeside, dual wheels, minimum length of bed, 12 feet. Four-wheel drive preferable. International type truck used in current studies. Floor plan for supporting equipment when in transportation is shown in fig. 10.
Number required: One.

SPECIFICATIONS FOR WATER HAULING TANK

Purpose: To provide a source of water for pre-wetting plots and for conducting infiltration and erosion tests.
Design and materials:
Type -- Standard round tank
Size -- Diameter - 3 feet
Length - 8 feet
Capacity - 425 gallons
Weight - tank filled with water - approx. 2 tons.
General requirements: Materials of ends and sides to be galvanized iron and seams welded. Standard manhole intake to be provided on side of tank, midway between ends. Manhole cover to be fastened to tank by bolts equipped with wing nuts (see figures 3 and 7). A 1½-inch outlet with standard pipe threads to be provided at one end of tank near side and 180° from manhole location. Two splash plates, spaced equidistant from ends, dividing tank into thirds. Plates to come within 6 inches of top and bottom of tank. Sizes and metal gage can vary to meet specification of standard tank.
Number required and 1947 cost: One storage tank - $200.

SPECIFICATION FOR APPLICATOR

Purpose: To provide a rigid support for mounting sprinkler nozzles so that when frame is properly leveled the nozzles are set automatically and accurately at the proper angle and distance from plot to produce a uniform rainfall pattern of prescribed intensity.

Design and materials: Design of applicators is shown in figs. 18 and 19.

Material required for one applicator:

16.5 lineal feet 1"x1" galvanized angle iron
2.0 lineal feet 3/4"x3/4" galvanized angle iron
2.0 lineal feet 1½"x¼" strap iron
5.5 lineal feet 3/4" galvanized iron pipe
0.5 lineal feet 1/2" galvanized iron pipe
1 90°-3/4" galvanized iron pipe elbow
3 90°-1/2" galvanized iron pipe elbows (street)
3 1/2" stop and waste water cocks
3 standard type "F" nozzles

Number required and 1947 cost:

Two for a complete set
$26 per unit, applicator with stopcocks but without nozzles (material and labor)

SPECIFICATION FOR TYPE F NOZZLE

Purpose: To provide a spray of known intensity and energy for simulating natural rainfall.

Design and materials: Design of Type F nozzle is shown in figs. 19a and 19b. Figure 19a shows the nozzle in detail and in assembly. The thread on the entrance end should be 1-inch outside diameter, twenty threads per inch to fit the female thread of the Grinnell 1.5 nozzle base. Disks and sleeves should have a sliding fit with inner wall of the shell. Figure 19b illustrates a suggested method of forming the entrance helix.

The nozzle is constructed entirely of brass.

Number required and 1940 cost:

Six for a complete set
$7 per unit

SPECIFICATION FOR PLOT FRAME AND TRASH COLLECTOR

Purpose: To enclose sampling areas with a frame of fixed dimensions, 12"x30.5", from which water runoff and sediment is collected and measured. Slope length of frame is constant but projected length varies some.

Design: The design of plots is shown in fig. 20.

Material required for one plot frame:
5 sq. ft. of 14-gage galvanized sheet iron
7 lineal feet 3/4"x3/4" galvanized angle iron
3 lineal feet 3/4"x1/8" galvanized strap iron
4 lineal feet 1/2" standard galvanized iron pipe
2 lineal feet 3/4" rubber garden hose

Material required for trash collector:
0.5 sq. ft. 20-gage galvanized sheet iron
0.5 sq. ft. 14-mesh galvanized wire

Number required and 1947 cost:
Two minimum; four preferable
Plot frame (material and labor) = $20 per unit
Plot screen (material and labor)= $ 1 per unit

SPECIFICATION FOR RAIN GAGE TROUGH

Purpose: To provide a continuous measure of rainfall intensity during the entire 50-minute test period because substantial variations in rate of application cannot be eliminated.

Design and materials: The design of rain trough is given in fig. 21.

Material required for one rain trough:
6 sq. ft. 16-gage galvanized sheet iron
8 lineal feet 3/4"x3/4" galvanized angle iron
6.5 lineal feet 1/2" standard galvanized iron pipe
1 90° elbow, 1/2" standard galvanized iron pipe
1 Tee coupling, 1/2" standard galvanized iron pipe
2 lineal feet 3/4" rubber garden hose

Number required and 1947 cost:
Two for each complete outfit
$20 per unit (material and labor)

SPECIFICATION FOR RAIN PAN AND SPLASH SCREEN

Purpose: To determine the correction factor for adjusting rain intensity measured in troughs to that falling over plot area during test periods. Use of a conversion factor with trough gage intensity yields plot rain intensities with less than 1 or 2 percent error. Splash screen prevents water loss from pan during test run.

Design and materials: Design of rain pan and splash screen is shown in fig. 22.

Material required for one rain pan:
6 sq. ft. 20-gage galvanized sheet iron
7 lineal feet 3/4"x3/4" galvanized angle iron
3 lineal feet 3/4"x1/8" galvanized strap iron
4 lineal feet 1/2" standard galvanized iron pipe
2 lineal feet 3/4" rubber garden hose

Material required for one splash screen:
3 sq. ft. 14-mesh galvanized wire screen
1.5 sq. ft. 24-gage galvanized sheet iron

Number required and 1947 cost:
Two rain pans and two splash screens per infiltrometer unit
Calibration pan (materials and labor) - $15 per unit
Splash screen (materials and labor) - $ 5 per unit

SPECIFICATIONS FOR CIRCULATING SYSTEM

Purpose: To provide a means for pumping clear water free of any foreign material from streams, irrigation ditches, lakes, reservoirs, ponds, and other suitable water supply sources either into water storage tank or directly to rainfall nozzles at plot locations. To also furnish a means of pumping clear water from tank to nozzles at a uniform steady rate.

Design and materials:

Tank to pump hookup: Design is shown in fig. 6.

Material required:

5 1½" close pipe nipples (1½"-2" length)
2 1½" long pipe nipples (8" length)
1 1½" tee
2 1½" 90° street elbows
1 1½" union
1 1½" pipe strainer (fre-flow, Fisher #260)
(Above pipe and fittings to be galvanized)
2 1½" gate valves
1 1-3/4" rubber radiator hose (6" length)
2 worm gear clamps for above hose

Pump to rainfall applicator hookup: Shown in figs. 2 and 7.

Material required:

1 1½" pressure relief valve - cast brass (PT-Pacific Marine-PA270)
1 1½" unit siamese valve - (Pacific Marine-PA272)
140 feet 1½" pacolized linen forestry fire hose with aluminum couplings (2 sections, 50'; 1 section, 25'; 1 section 15' length of hose)
2 1½" to 3/4" reducers
2 3/4" pipe strainers - (Fisher #260 fre-flow or Trane strainer)
2 3/4" globe needlepoint valves (standard brass)
315 feet 3/4" rubber garden hose (four 50' lengths equipped with male and female couplings; two 50' lengths with female couplings only; and one 15' length with one female coupling only)
1 5/8" standard automobile rubber heater hose (12' length)

Number required and 1948 cost:

One circulating system per unit

Tank to pump hookup (material only)	$35 per unit
Pump to applicator hookup (material only)	$80 per unit

SPECIFICATIONS FOR WINDBREAKER TENTS

Purpose: To prevent wind disturbance during runs so as to facilitate application of a uniform rain pattern over plot area and rain troughs.

Design and materials: Windbreaker tent when set up is 6 x 6 feet square and 7 feet high (figs. 8, 9, 13 and 15). Hemmed and reinforced slit openings are made 2½ feet from bottom and 3 feet from front end of tent.

Material required for one windbreaker tent:

168 sq. ft. 12-oz. canvas; dimensions (7'x24') provided with complete hem and grommets on both 7-foot ends.
4 pieces pine (2"x2"x7½') or 7½' light weight aluminum posts
8 laths (used with pine posts)
3 snaps
16 metal tent stakes, 20 in. long, constructed of 1¼"x1¼" angle iron and reinforced at top with an 8" length of 1/2" iron rod (see fig. 4)
3 lbs. 1/4" guy ropes

Number required and 1947 cost:

Two minimum; four recommended
One tent complete (Materials and labor) - $30

Recommended changes:

Use aluminum poles and lightweight but durable windproof cloth or plastic, if available.

SPECIFICATIONS FOR SEDIMENT CANS

Purpose: To provide a means for collecting all surface runoff water from plots and to allow settling of sediment; for oven-dry weight measurement.

Design and materials:

Three sizes of cans preferable (capacities about 4, 6 and 8 gallons), tapered sides to allow nesting cans for compactness.
24-gage galvanized sheet iron used.
Dimensions:
1 can - 9" and 11" diameter, 12" height
1 can -10" and 12" diameter, 14" height
1 can -11" and 13½" diameter, 15½" height

Number required and 1949 cost:

10 4-gallon cans (material and labor) - $20.00
10 6-gallon cans (material and labor) - $22.50
10 8-gallon cans (material and labor) - $27.50

Recommended changes:

Use 16-gage aluminum if available.

SPECIFICATIONS FOR VEGETATION AND SOIL PLOT GRID

Purpose: To facilitate measuring portion of plot area covered by soil, rocks, live and dead organic materials.

Design and materials:

Dimension--12"x30.5" grid area (inside pipe)
12.5"x31" over-all area (outside pipe)
8 lineal feet 1/8" galvanized iron pipe
3 square feet 1" x 2" hardware cloth

Number required and 1949 cost:

1 minimum; 2 preferred
1 grid - $4

SPECIFICATION FOR PRESSURE GAGE

Purpose: To aid in maintaining a steady and uniform discharge through nozzles during test runs.

Design and materials:

Dimensions: 3½" face, light weight; 0 to 30 pound range, 1/4 lb. graduations, bronze bushed movements; rustproof; and standard 1/4" female connection gage to be sensitive to 1/16-lb. fluctuations in pressure and to have 1/2 pound accuracy over entire range.

Number required and 1947 cost:

Two gages
One gage - $7

SPECIFICATION FOR SEDIMENT TRAYS

Purpose: To facilitate evaporation of residual runoff water and collection of sediment.

Design and materials:

Dimension - 24"x24"x2-3/4" with tapered sides to allow nesting trays for compactness. Use a 30"x30" sheet, side slopes 3", bottom 2' square, vertical depth about 2-3/4" (28-gage galvanized sheet iron)

Number required and 1948 costs:

20 trays (material and labor) - $35

SPECIFICATION FOR INITIAL WETTING SCREENS

Purpose: To reduce impact force of raindrops and prevent splash erosion during initial wetting of plots.

Design and materials:

Dimension - 21"x40"
10.2 lineal feet, 1/8" galvanized iron pipe
6 sq. ft. 16-mesh galvanized wire screen

Number required and 1948 cost:

Two screens per unit
One screen - $5

SPECIFICATIONS FOR TAMPING BLOCK

Purpose: Used in forcing plot frame into soil. Angle iron guides prevent plot walls from spreading during tamping process.

Design and materials:

Dimension--2"x10"x15" rough oak.
2 pieces--1"x1"x1/8"x10" angle iron--bolted to blocks for guides
6-3/8"x2½" carriage bolts

Number required and 1948 cost:

Three blocks
Each block - $2

SPECIFICATIONS FOR CANVAS PLOT COVERS

Purpose: To prevent evaporation-transpiration losses between initial wetting and test run.

Design and materials:

Dimension--6'x6' or similar size
Material--12-ounce double filled canvas, all edges hemmed.

Number required and 1947 cost:

12 covers, minimum.
Unit cost--$3

SPECIFICATIONS FOR TANK CRADLE AND SUPPORT BANDS

Purpose: To rigidly fasten water storage tank to truck bed. To also raise tank above truck bed so as to provide additional storage space for equipment.

Design and materials:

Tank cradle--3 pieces 6"x12"x6' rough Douglas fir, cut on upper side to fit tank.
3-3/16"x2½"x1' strap-iron bands with hole at both flanged ends.
3-3/16"x2½"x6' strap-iron bands with hole at both flanged ends.
6-½"x6" machine bolts
21 lineal feet pulley belting for insertion between bands and tank.

1948 cost:

Complete installation (labor and materials) - $30

SPECIFICATIONS FOR OTHER ACCESSORY EQUIPMENT

1. Truck side boards for speedup in field operation--constructed of 1"x12" oak and carriage bolts--1948 cost of materials--$7. (see figs. 3, 6 and 7 for design).
2. 100 cylindrical rain gage cans, standard seamless brass tubing. Can dimension--0.992" diameter; 4" depth. 1947 cost--$20.
3. One truck stepladder for speedup and safety in loading and unloading equipment (see figs. 1, 6 and 7 for design). 1949 cost--$8.
4. Tool box and metal frame support (figs. 2, 3, 6, and 10). 1949 cost (material and labor)--$20
5. 40 feet 1/8" rubber siphon hose--$2. Used in draining sediment cans.

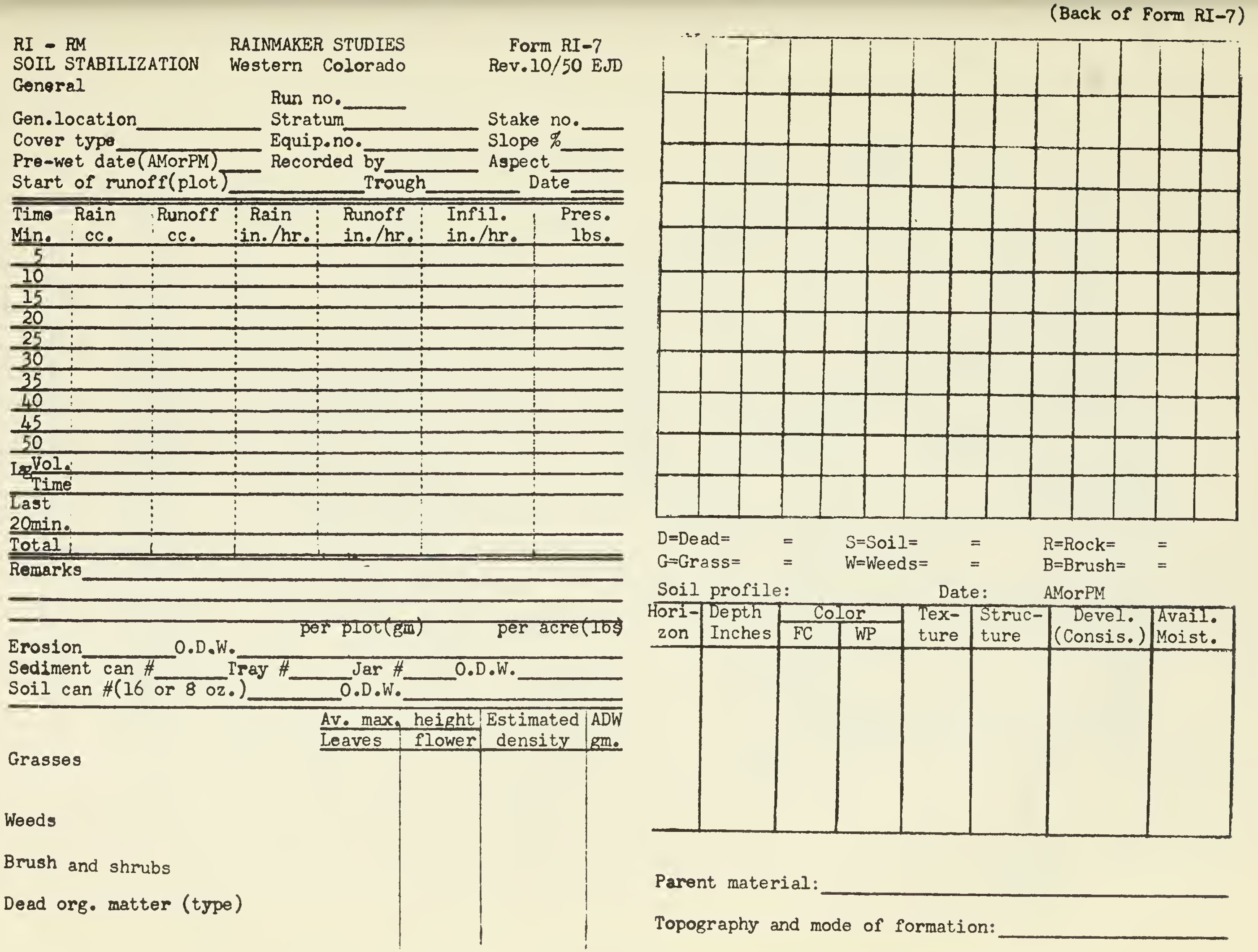
6. Two 15" aluminum pipe spirit levels, used for leveling plot frame and rainfall applicator and plumbing nozzles. 1949 unit cost--$8.
7. 200 friction-type 8- and 16-ounce soil cans for collection of sediment. 1949 cost--$30.
8. One Abney percent level for determining slope of each plot. 1949 unit cost--$10.
9. One pair field glasses, 6 x 30, for reading pressure gages during test runs. 1949 cost--$35.
10. Two stop watches for timing start, end, and 5-minute intervals during each run. One watch per operator. 1949 unit cost--$10.
11. One soil-sampling set (tube and hammer or auger). Cost--$20.
12. Three Army rectangular, Jerry type gasoline cans for hauling gasoline and oil. Unit cost--$3.
13. Three 1,000 ml. lucite graduates with carrying box. Total cost--$20.
14. Eight 1-gallon cans used for collecting runoff from plots. No cost.
15. One pocket compass. Cost--$15.
16. Two field tatums or clip boards. Total cost--$2 to $5.

Total cost--approximately $250.

SPECIFICATION AND COST OF TOOLS

One 4-lb. sledge hammer
Two 4-inch triangular trowels
One pair grass shears with offset handles
One 10-inch and 12-inch adjustable crescent wrench
One brush cutter
Two 6-inch triangular trowels sharpened on sides
Three shovels ("Lady type" - Forest Service
One pair standard 6-inch pliers
One 8-inch screwdriver
One 10-inch and 14-inch pipe wrench
One claw hammer
One hand axe
One oil spout can
One dust brush
One whisk broom
10 feet - web belt

Total cost--$25 to $30.



(Back of Form RI-7)

RI - RM
SOIL STABILIZATION
General

RAINMAKER STUDIES
Western Colorado

Form RI-7
Rev.10/50 EJD

Run no.______

Gen.location____________ Stratum____________ Stake no.____
Cover type____________ Equip.no.____________ Slope %______
Pre-wet date(AMorPM)____ Recorded by__________ Aspect______
Start of runoff(plot)____________ Trough__________ Date______

Time Min.	Rain cc.	Runoff cc.	Rain in./hr.	Runoff in./hr.	Infil. in./hr.	Pres. lbs.
5						
10						
15						
20						
25						
30						
35						
40						
45						
50						
~~Lg~~ Vol. Time						
Last 20min.						
Total						

Remarks____________________________________

per plot(gm) per acre(lbs)
Erosion________ O.D.W.____________________
Sediment can #______ Tray #______ Jar #______ O.D.W.______
Soil can #(16 or 8 oz.)__________ O.D.W.______________

	Av. max. height Leaves	flower	Estimated density	ADW gm.
Grasses				
Weeds				
Brush and shrubs				
Dead org. matter (type)				

D=Dead= = S=Soil= = R=Rock= =
G=Grass= = W=Weeds= = B=Brush= =

Soil profile: Date: AMorPM

Hori-zon	Depth Inches	Color		Tex-ture	Struc-ture	Devel. (Consis.)	Avail. Moist.
		FC	WP				

Parent material:____________________

Topography and mode of formation:____________________

Figure 17.—Field form used with Rocky Mountain infiltrometer (RI-7)

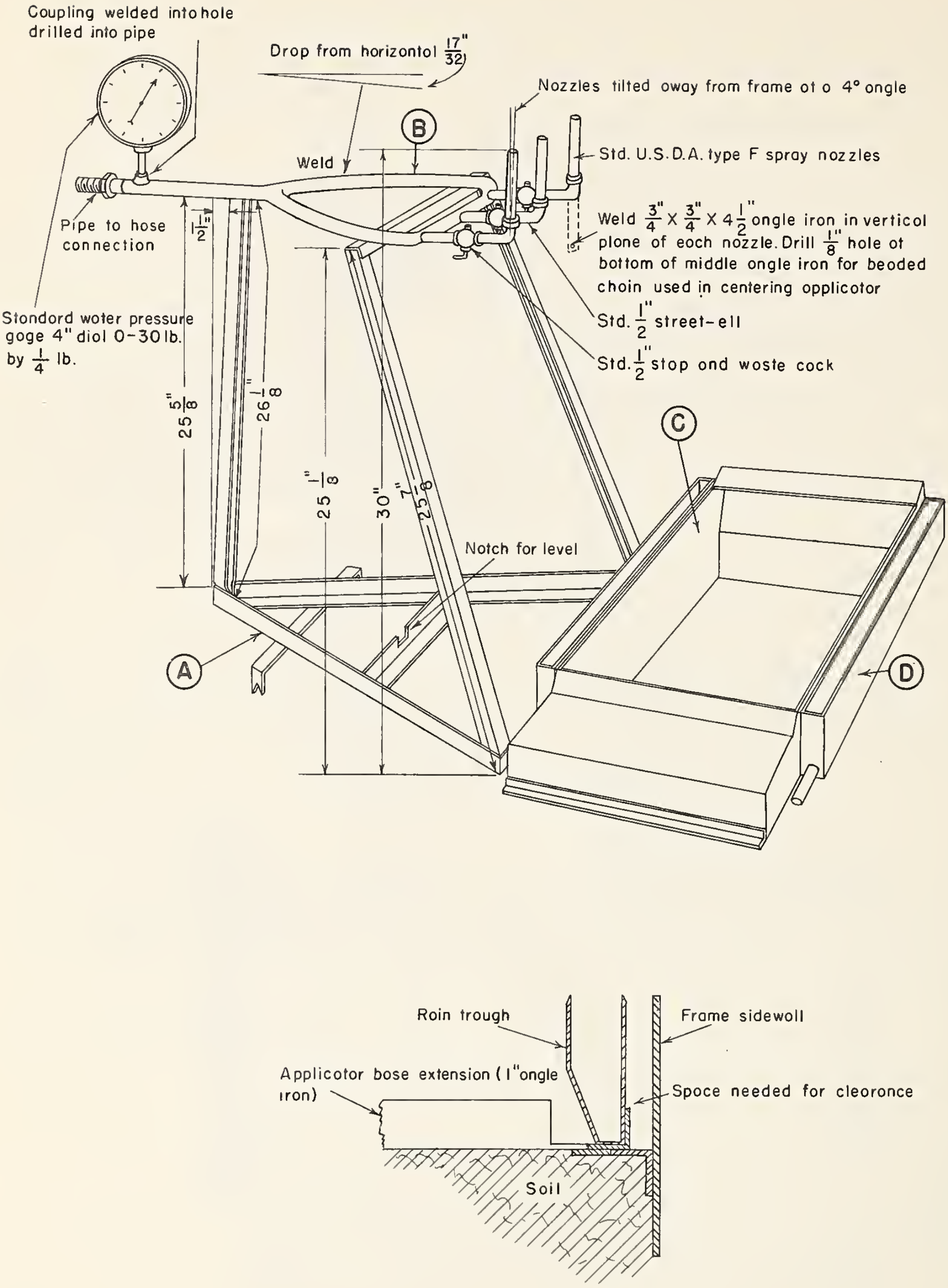
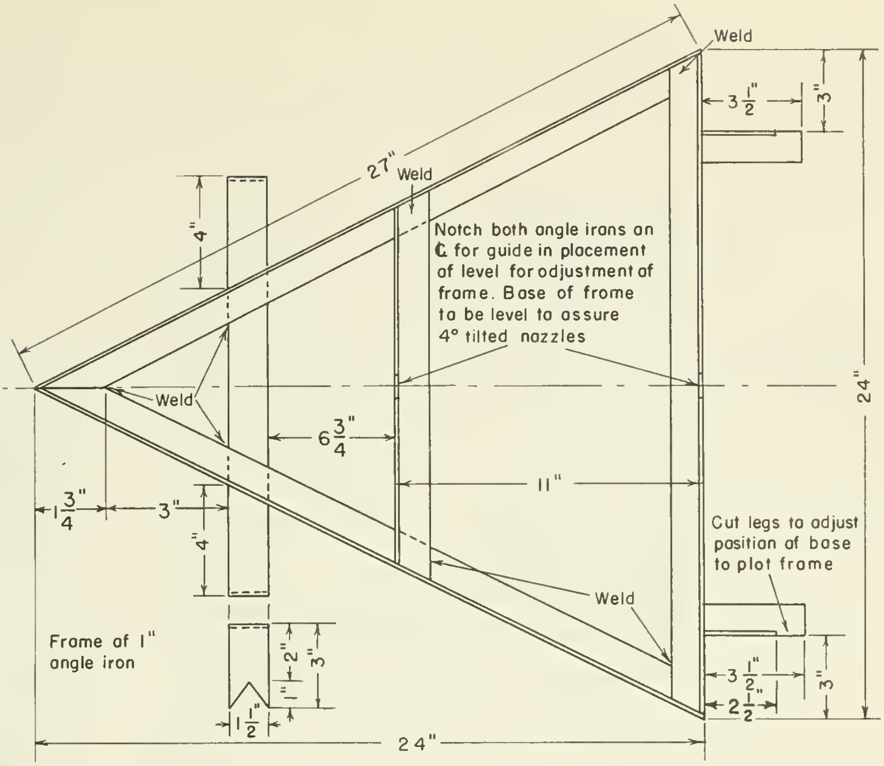
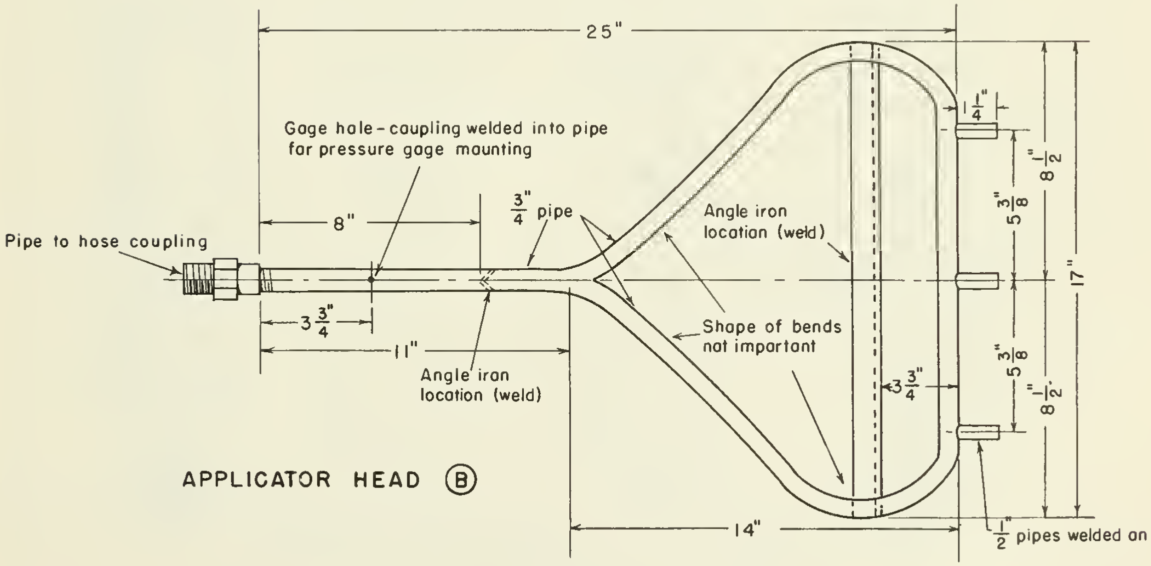

Coupling welded into hole drilled into pipe
Drop from horizontal 17/32"
Nozzles tilted away from frame at a 4° angle
B
Weld
Std. U.S.D.A. type F spray nozzles
Weld 3/4" X 3/4" X 4 1/2" angle iron in vertical plane of each nozzle. Drill 1/8" hole at bottom of middle angle iron for beaded chain used in centering applicator
Std. 1/2" street-ell
Std. 1/2" stop and waste cock
Pipe to hose connection
1 1/2"
Standard water pressure gage 4" dial 0-30 lb. by 1/4 lb.
25 5/8"
26 1/8"
25 1/8"
30"
25 7/8"
C
Notch for level
A
D
Rain trough
Frame sidewall
Applicator base extension (1" angle iron)
Space needed for clearance
Soil

FIG. 18 - ASSEMBLY OF INFILTROMETER FRAME "C", RAIN TROUGHS "D", AND RAINFALL APPLICATOR "A", "B"

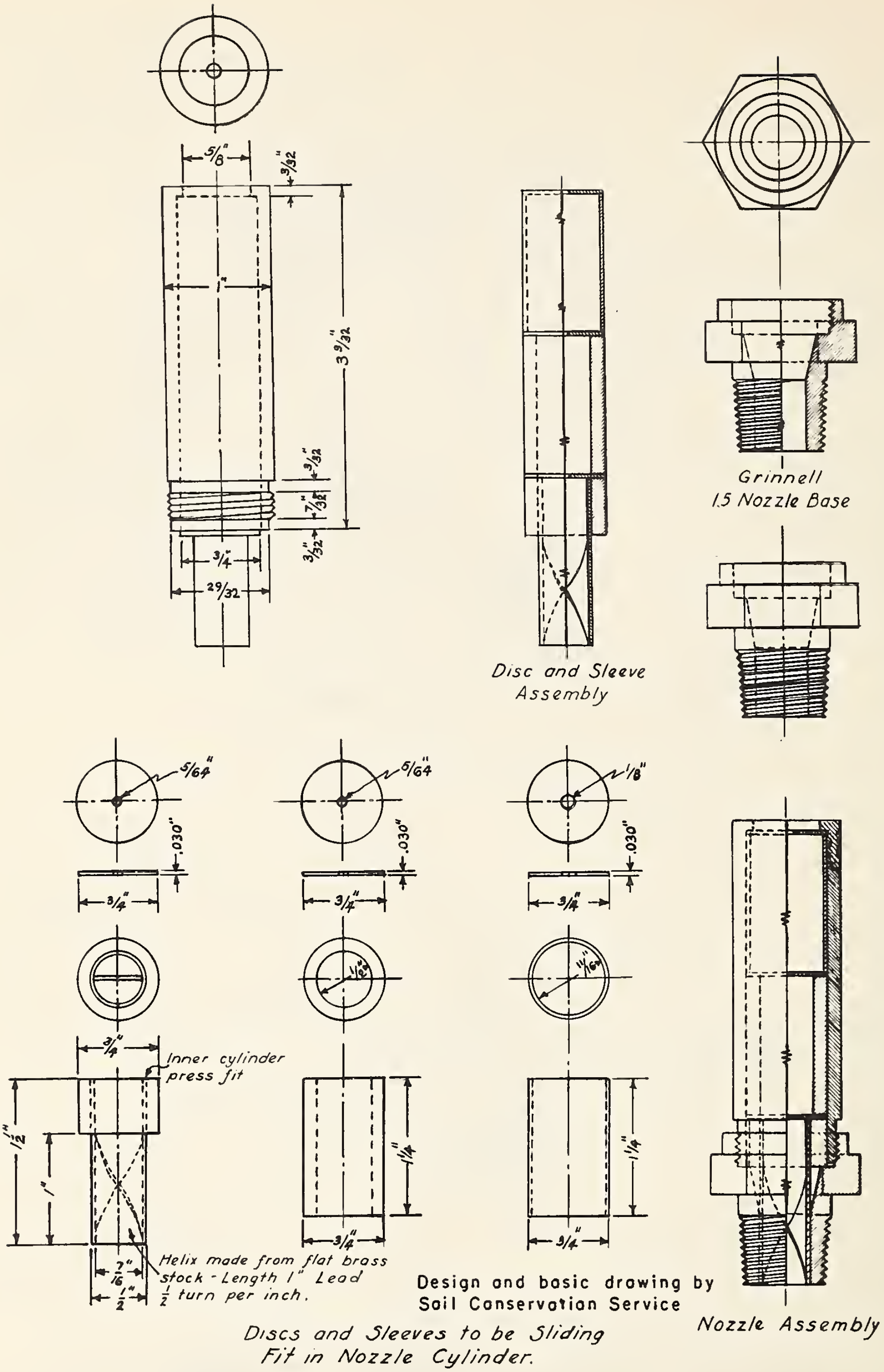

Weld
27"
Weld
4"
Notch both angle irons on ℄ for guide in placement of level for adjustment of frame. Base of frame to be level to assure 4° tilted nozzles
3 1/2"
3"
24"
Weld
6 3/4"
11"
1 3/4"
3"
4"
Cut legs to adjust position of base to plot frame
Weld
Frame of 1" angle iron
2"
3"
1"
1 1/2"
3 1/2"
2 1/2"
3"
24"

APPLICATOR BASE Ⓐ


25"
Gage hole - coupling welded into pipe for pressure gage mounting
8"
3/4 pipe
Angle iron location (weld)
1 1/4"
8 1/2"
5 3/8"
17"
Pipe to hose coupling
3 3/4
11"
Angle iron location (weld)
Shape of bends not important
3 3/4
5 3/8"
8 1/2"
14"
1/2" pipes welded on

APPLICATOR HEAD Ⓑ

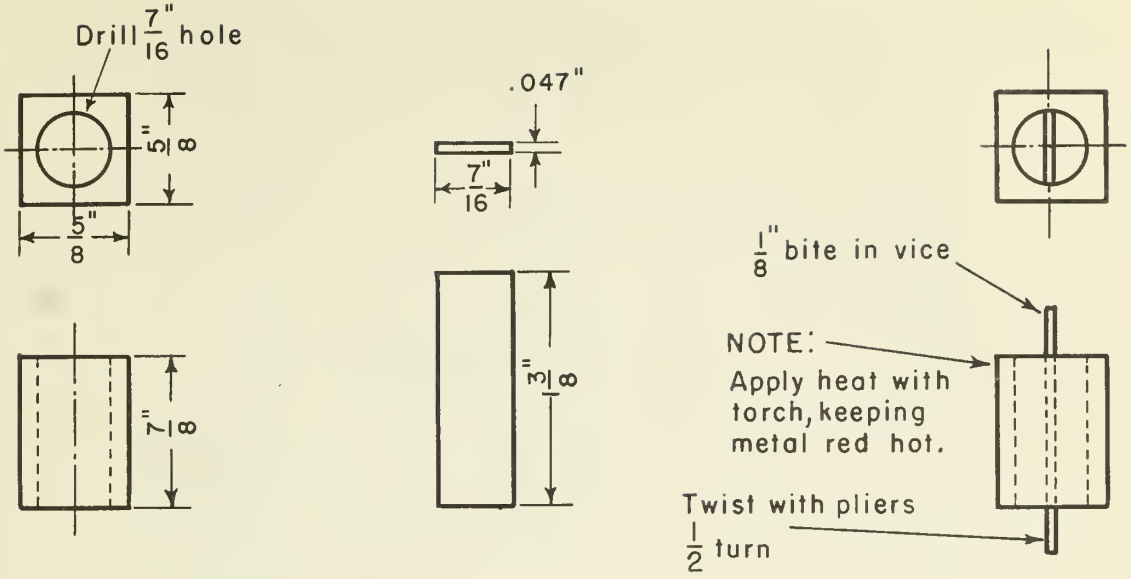
FIG. 19 — RAINFALL APPLICATOR



Design and basic drawing by Soil Conservation Service

Discs and Sleeves to be Sliding Fit in Nozzle Cylinder.

FIG. 19a-CONSTRUCTION DETAIL OF TYPE F NOZZLE



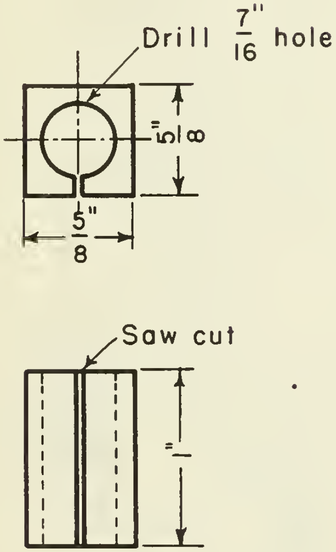
NOTE: Apply heat with torch, keeping metal red hot.

Twist with pliers 1/2 turn

DIE FOR ALIGNING HELIX

SHEET BRASS STOCK

METHOD OF TWISTING HELIX



SUGGESTED DIE FOR CUTTING HELIX TO LENGTH

NOTE:
Clamp die in vice, cut helix to length and trim edges with file.

Design and basic drawing by Soil Conservation Service.

FIG. 19b–SUGGESTED METHOD OF MAKING HELIX FOR TYPE F NOZZLE

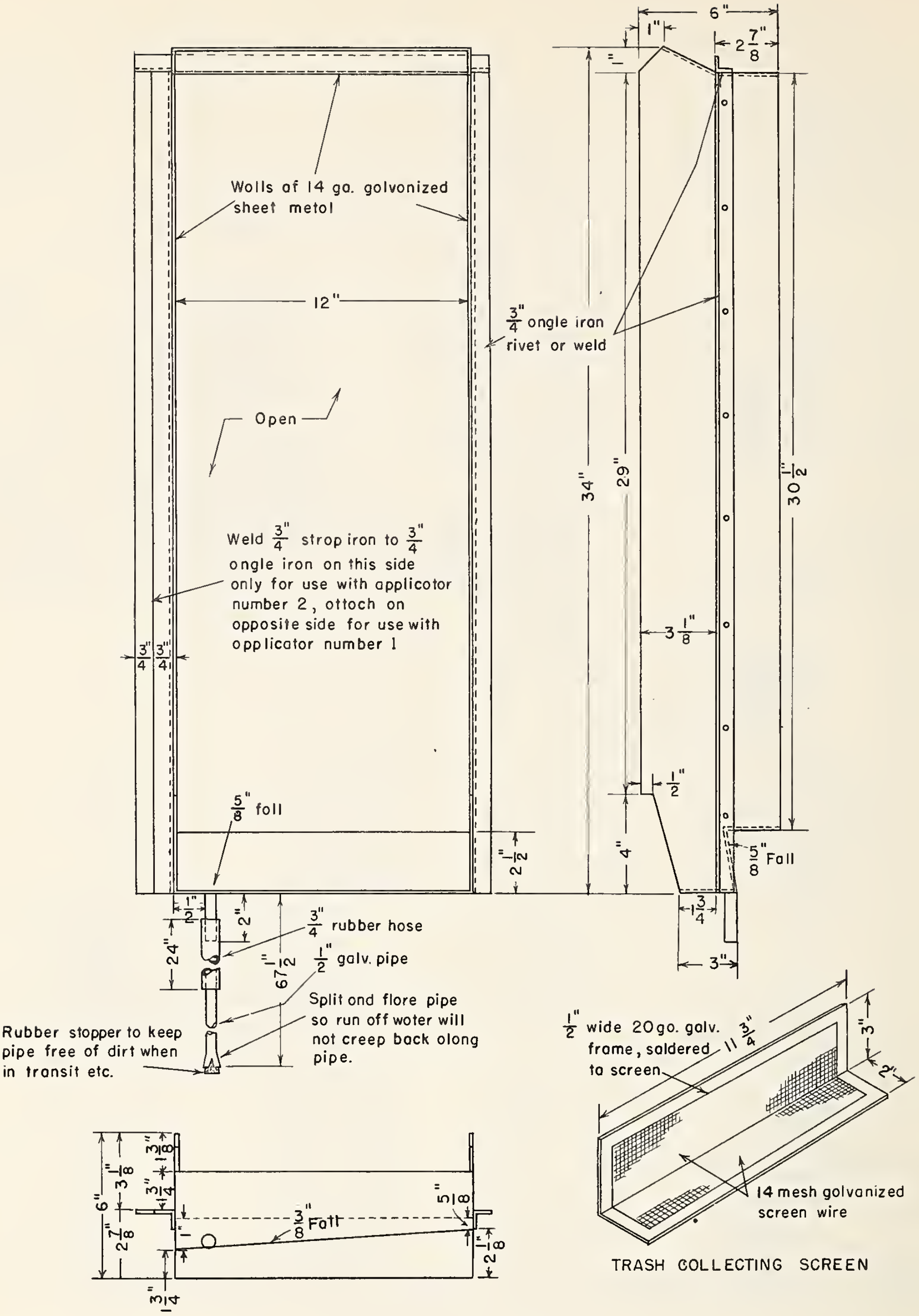
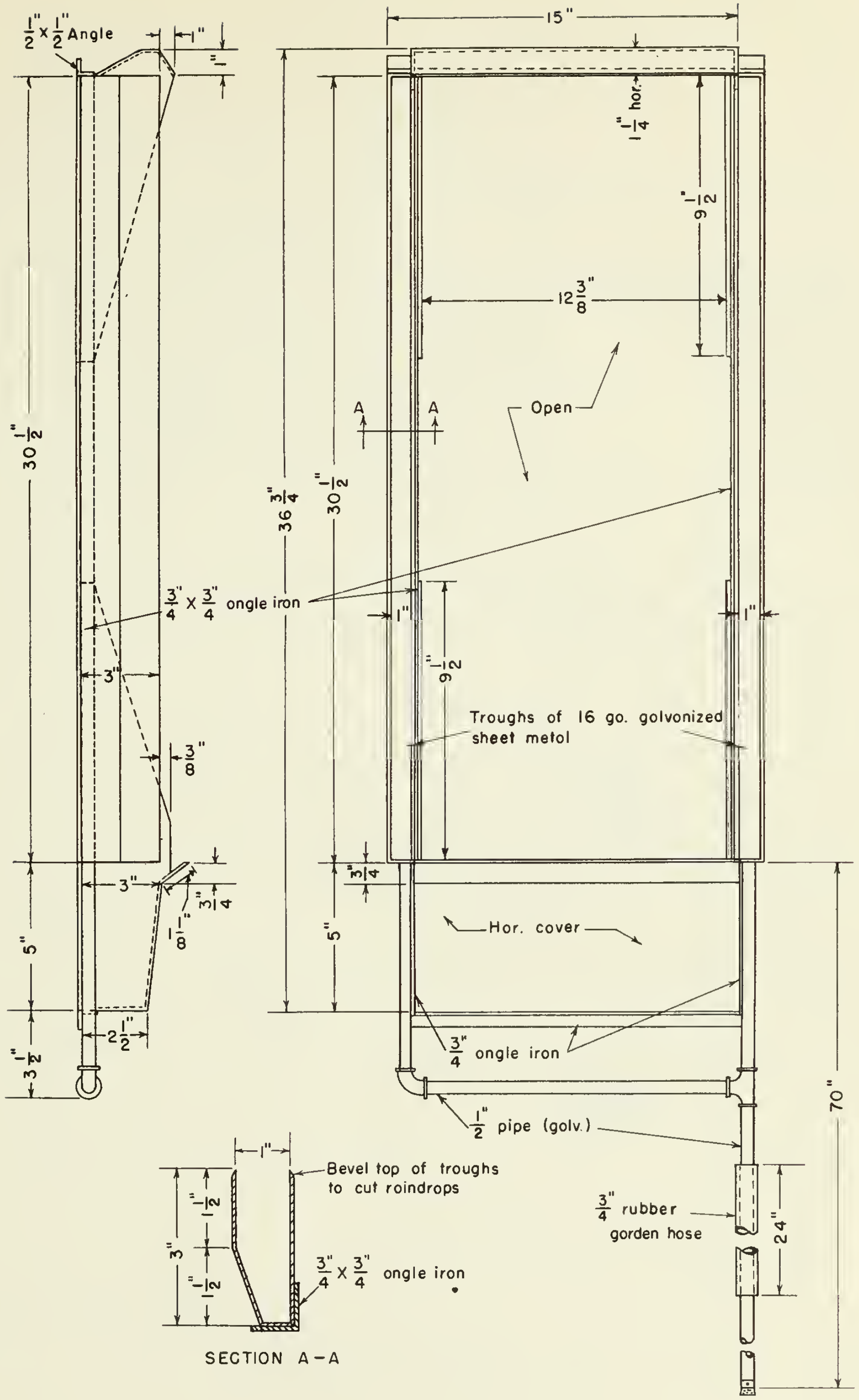
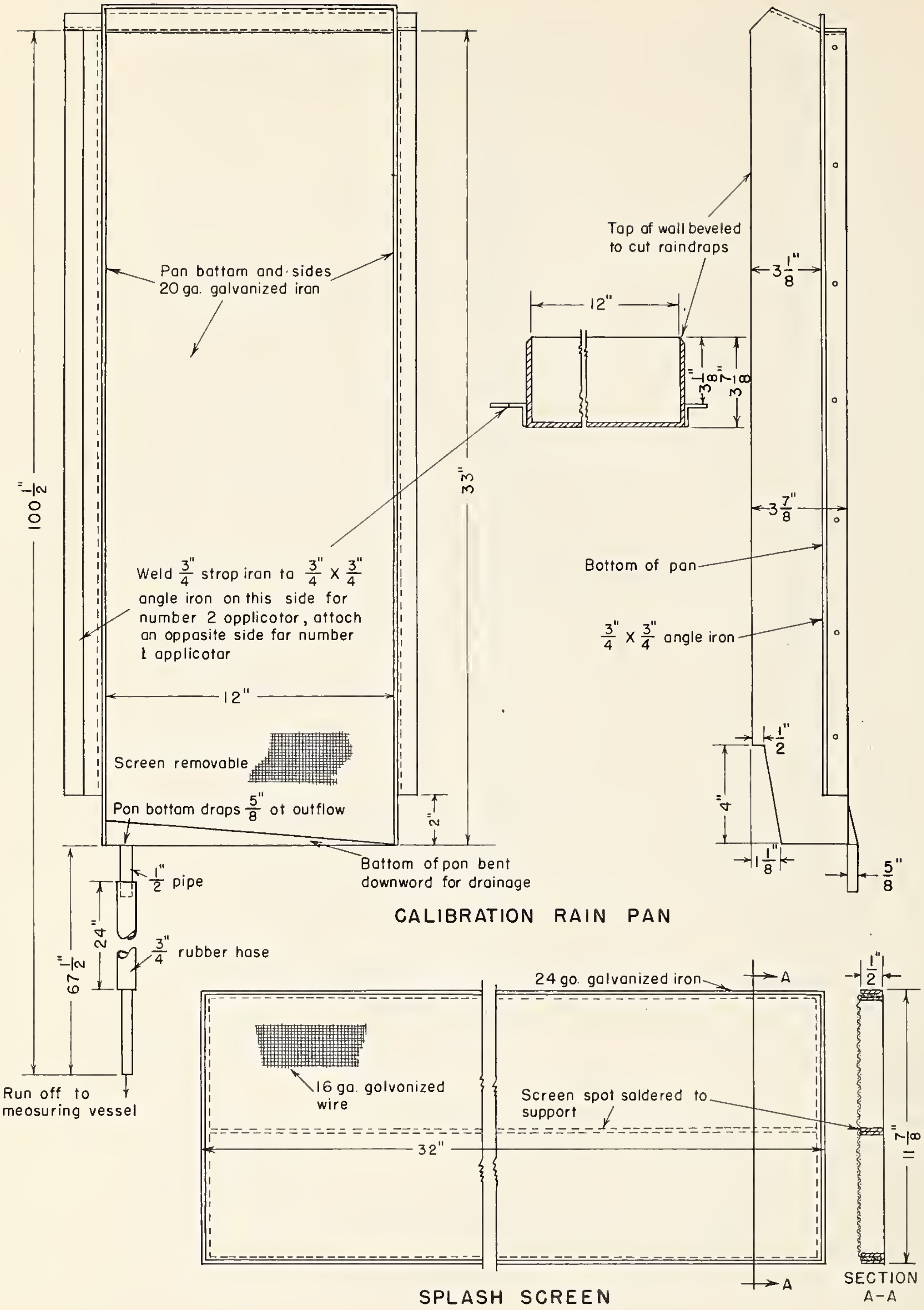

6"
1"
2 7/8"
Walls of 14 ga. galvanized sheet metal
12"
3/4" angle iron rivet or weld
Open
34"
29"
30 1/2"
Weld 3/4" strap iron to 3/4" angle iron on this side only for use with applicator number 2, attach on opposite side for use with applicator number 1
3/4" 3/4"
3 1/8"
1/2"
5/8" fall
2 1/2"
4"
5/8" Fall
1 3/4
3"
1/2"
2"
24"
3/4" rubber hose
1/2" galv. pipe
67 1/2"
Split and flare pipe so run off water will not creep back along pipe.
Rubber stopper to keep pipe free of dirt when in transit etc.
1/2" wide 20 ga. galv. frame, soldered to screen
11 3/4"
3"
2"
14 mesh galvanized screen wire
TRASH COLLECTING SCREEN
6"
3 1/8"
1 1/8"
3/4"
2 7/8"
1"
3/8" Fall
5/8"
2 1/8"
3/4"

FIG. 20 - PLOT FRAME AND SCREEN "C"


$\frac{1}{2}$" x $\frac{1}{2}$" Angle
1"
1"
15"
$1\frac{1}{4}$" hor.
$9\frac{1}{2}$"
$12\frac{3}{8}$"
Open
A
A
$30\frac{1}{2}$"
$36\frac{3}{4}$"
$30\frac{1}{2}$"
$\frac{3}{4}$" x $\frac{3}{4}$" ongle iron
1"
1"
$9\frac{1}{2}$"
3"
Troughs of 16 go. golvonized sheet metol
$\frac{3}{8}$"
3"
$\frac{3}{4}$"
$\frac{3}{4}$"
$1\frac{1}{8}$"
5"
5"
Hor. cover
$2\frac{1}{2}$"
$3\frac{1}{2}$"
$\frac{3}{4}$" ongle iron
$\frac{1}{2}$" pipe (golv.)
70"
1"
Bevel top of troughs to cut roindrops
$1\frac{1}{2}$"
3"
$1\frac{1}{2}$"
$\frac{3}{4}$" x $\frac{3}{4}$" ongle iron
$\frac{3}{4}$" rubber gorden hose
24"

SECTION A-A

FIG. 21 - RAIN GAGE TROUGH "D"



Top of wall beveled to cut raindrops
12"
1 3/8"
7 3/8"
3 1/8"
3 7/8"
Bottom of pan
3/4" X 3/4" angle iron
1/2"
4"
1 1/8"
5/8"
Pan bottom and sides 20 ga. galvanized iron
100 1/2"
33"
Weld 3/4" strap iron to 3/4" X 3/4" angle iron on this side for number 2 applicator, attach on opposite side for number 1 applicator
12"
Screen removable
Pan bottom drops 5/8" at outflow
2"
Bottom of pan bent downward for drainage
1/2" pipe
24"
67 1/2"
3/4" rubber hose
Run off to measuring vessel
CALIBRATION RAIN PAN
24 ga. galvanized iron
A
16 ga. galvanized wire
Screen spot soldered to support
32"
A
1/2"
11 7/8"
SECTION A-A
SPLASH SCREEN

FIG. 22 - RAIN PAN AND SPLASH SCREEN USED IN CALIBRATION

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